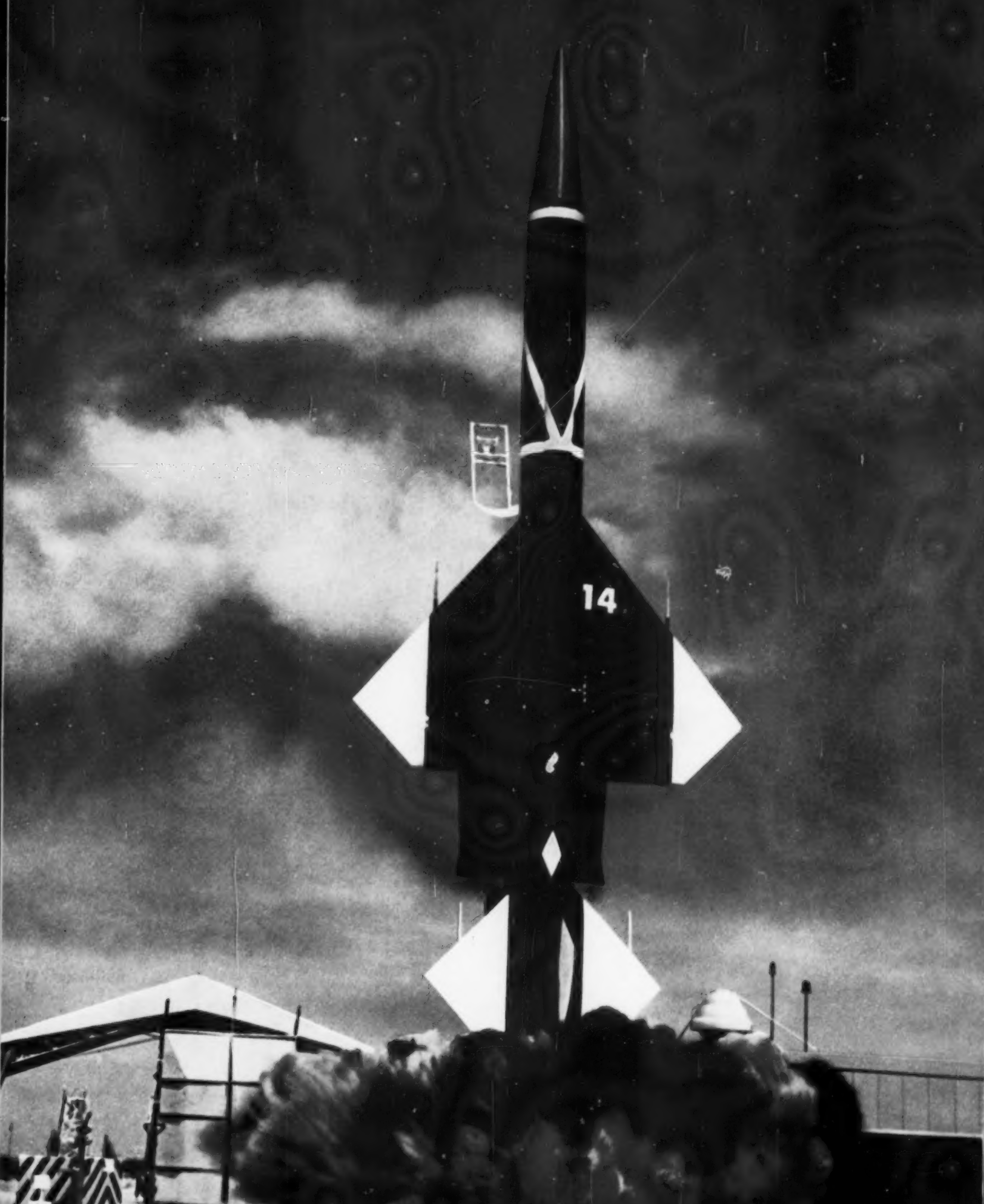
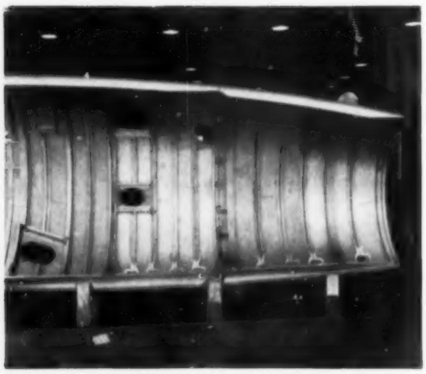
Metal Progress



For improved strength / weight in the...

DC-8

1667 TITANIUM PARTS!



***Access door** on DC-8 engine assembly, fabricated entirely of titanium. Skin is .016" thick, ribs and longerons are .032" thick.*

Access doors on engine assemblies, pylon skirts, and hundreds of other structural parts on the Douglas DC-8 are fabricated from high strength, light weight, corrosion resistant titanium.

Mallory-Sharon service engineers have worked closely with Ryan Aeronautical Company engineers—a major supplier of parts and components for the DC-8. New high strength titanium alloys, improved methods of machining and forming, have been developed and employed. The result has been increasingly wide application of titanium's weight-saving advantages—*up to 57%* over stainless steel in many cases.

May we help *you* gain more benefit from titanium's unusual capabilities? Our experienced Service Engineering group is ready to assist you. Or write for new bulletin on Recommendations for Machining Titanium.

MALLORY MS SHARON

MALLORY-SHARON METALS CORPORATION · NILES, OHIO

Integrated producer of Titanium • Zirconium • Special Metals

Metal Progress

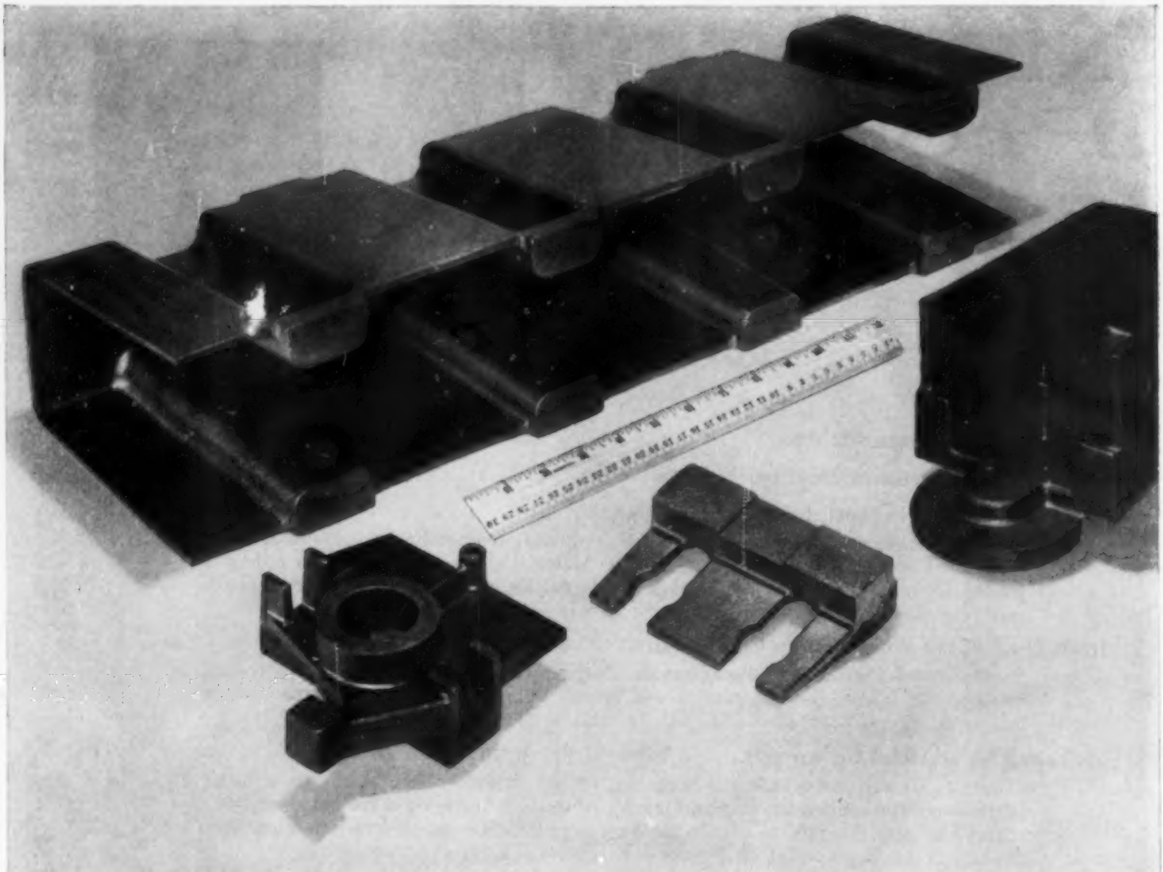
March 1959 . . . Volume 75, No. 3

Launching of the Bomarc; cover photograph courtesy Boeing Airplane Co.; details on p. 71.

Producing for the Supersonic Age

Table of Contents Continued on Page 3

**The coding symbols refer to the ASM-SLA Metallurgical Literature Classification, International (Second) Edition, 1958*



Electro-Alloys shell molded heat- and corrosion-resistant castings open a new range of applications where high dimensional accuracy, reduced machining cost, and superior finish are needed. Write
ELECTRO-ALLOYS DIVISION
1013 Taylor Street, Elyria, Ohio
for technical information.

AMERICAN Brake Shoe COMPANY

Metal Progress is published monthly by the American Society for Metals. Publication office Mt. Morris, Ill. Editorial and general offices 7301 Euclid Ave., Cleveland 3, Ohio. Entered as second class matter at the Post Office in Mt. Morris, Ill. Vol. 75, No. 3, March 1959.

Press Breaks...

AMONG THE MOST INTERESTING extracurricular activities of the Editor-in-Chief is acting as chairman of a group of 15 engineers and editors comprising the Atomic Energy Commission's Advisory Committee on Industrial Information, which in the last ten years has had a considerable influence in the change from a closed door, inherited from the Army-managed Manhattan Engineer District's atom bomb, to the open door to all information on power reactors, industrial use of reactive isotopes, health and safety -- everything but naval reactors and atomic weapons.

About 18 months ago this advisory committee, impressed by the overwhelming mass of information constantly becoming available about A.E.C. activities, recommended the quarterly publication of critical reviews of important developments in the various areas of the broad field. Three were in fact started, one on Power Reactor Technology, another on Reactor Fuel Processing, and the third on Reactor Core Materials -- all excellently done by appropriate experts. On a recent trip to Washington, the Editor was told that circulation of these quarterlies had doubled as a result of a mailing of a promotion piece to all members of the American Society for Metals! ASM'ers are apparently interested in atomic energy.

He was also asked whether, in his opinion, some effort should be made to find out how the readers of these quarterlies are using them, and he replied, "Five years from now, perhaps", on the basis that a periodical's early life depends upon the vision of the editor. If he has what it takes, the answer comes to him in the rate at which old readers renew their subscriptions. At any rate, the editor must lead -- he cannot follow, he cannot get detailed directions from his readers. The Editor-in-Chief is reminded of a survey made by the American Chemical Society of its members some years ago. Of a half-dozen leading questions about the conduct of the A.C.S. publications, 80 to 90% of the replies were, "Have no opinion on the matter."

That does not mean that he believes that readership surveys are useless. On the contrary, *Metal Progress* has for some years engaged the services of the Eastman Research Organization which specializes in this type of investigation, and every quarter we receive two large loose-leaf books, one containing the results of personal interviews with about 75 readers scattered all over the United States, and the other an expert analysis and appraisal of the readers' reactions to the current issue. Seventy-five interviews out of 32,500 readers is not a very big sample, but after you study the results of a score of such surveys, definite patterns emerge.

A common complaint by readers is that our digests (which, by the way, have as high readership as the much more attractively presented articles in the main editorial block) are in narrow-measure columns "hidden in among the advertising pages in the back of the book. Why?"

The reason is fairly simple. Magazines of mass circulation, with their uniform practice of starting each story with a luridly illustrated spread but continuing the text to the back of the book, have convinced many advertising agencies that fractional pages are the thing to buy. *Metal Progress* seldom carries over the text of an article to the back; we tailor the text and illustrations to fit the pages allotted. So the editors have a lot of holes to fill among the advertisements in the back of the book. Rather than fill them with stale, worked-over publicity handouts, we long ago decided to use critical digests of important articles, articles appearing elsewhere but of enough importance to the field of quality metal production and fabrication that we would have liked to print them originally. That's the reason. E.E.T.

Metal Progress

PUBLISHED BY AMERICAN SOCIETY FOR METALS
7301 EUCLID AVE., CLEVELAND 3, OHIO

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Other activities of American Society for Metals:

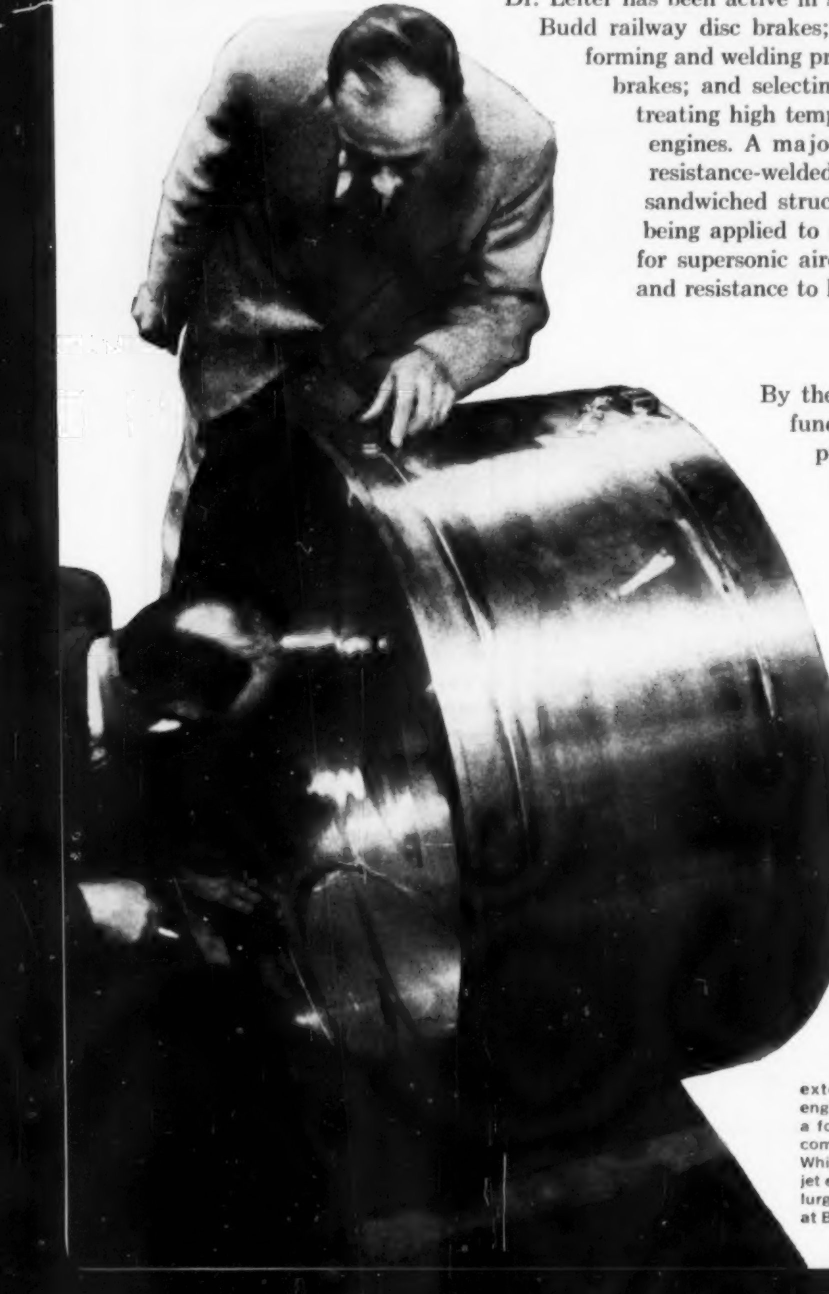
Publishes *Metals Handbook*, an encyclopedia of metals; *Metals Review*, news magazine; *Review of Metal Literature*, abstracting service; *Transactions*, scientific annual; Career technical books on metals.

Educational activities: Operates National, Western, and Southwestern Metal Congresses and Expositions; prepares and administers courses for Metals Engineering Institute for home, in-plant or American Society for Metals Chapter study.

Who cares what happens to METALS?

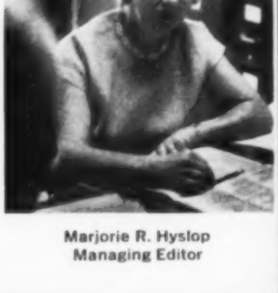
Dr. Ralph Leiter, for example, Director of Laboratories at Philadelphia headquarters of The Budd Company, metalworking fabricators of components and end-products for the railroad, automotive, aircraft, missile and atomic energy industries.

Together with his staff of engineers and metallurgists—metals engineers—Dr. Leiter has been active in such diverse areas as developing alloys for Budd railway disc brakes; determining the best mass production forming and welding processes for auto bodies, chassis, wheels and brakes; and selecting, testing, forming, fabricating and heat-treating high temperature parts for missiles, rockets and jet engines. A major achievement is their development of a resistance-welded stainless steel corrugation-reinforced and sandwiched structure called "Integrated Core Panel", now being applied to a critical nuclear program and under test for supersonic aircraft for its high strength-to-weight ratio and resistance to heat.

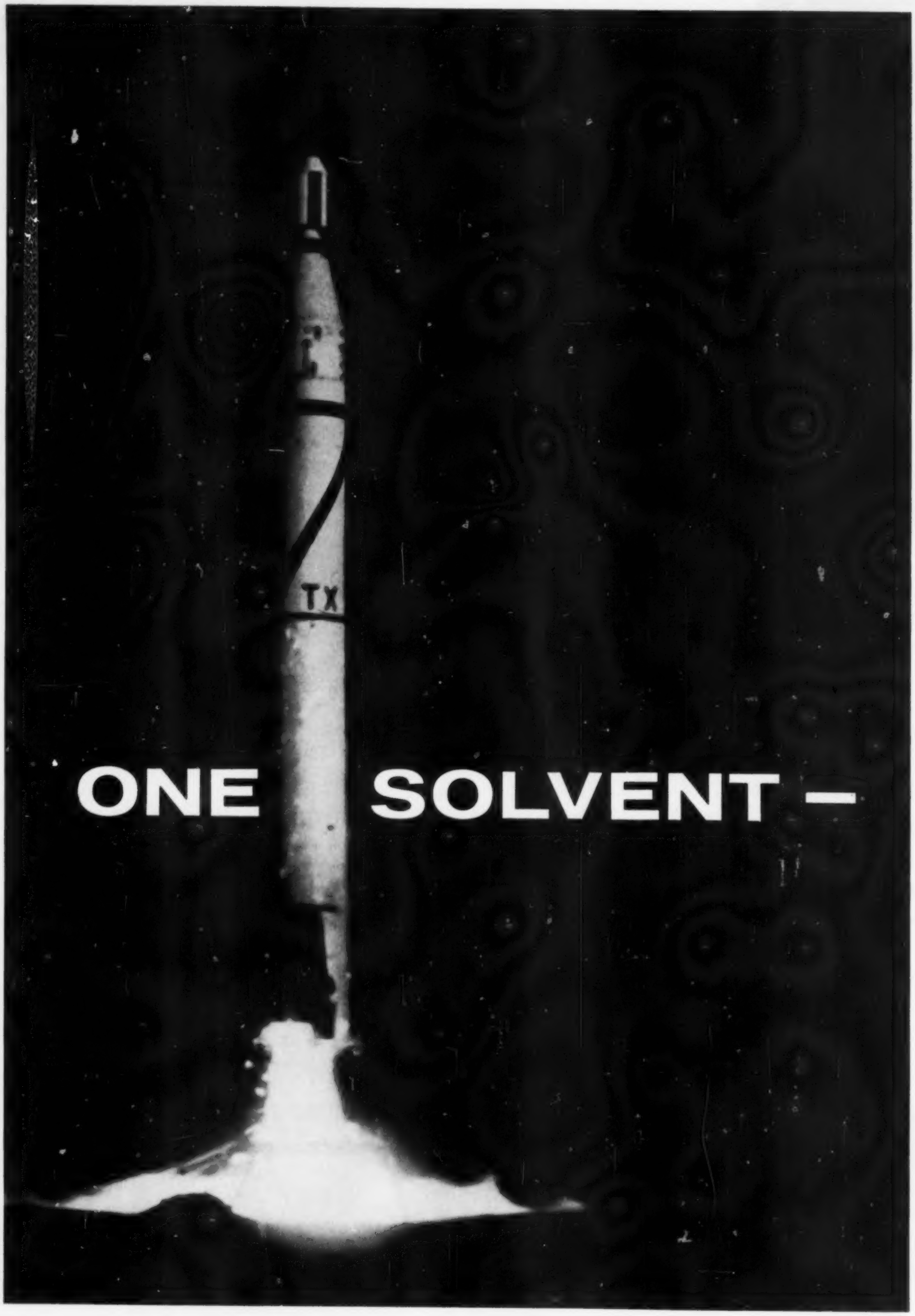


By the very nature of their jobs, these men are fundamentally concerned with specification and purchasing decisions affecting metals. They are part of a larger group of 30,000 metals engineers across the nation whose job it is, similarly, to care what happens to metals—to take an influential interest in metals selection, processing, fabrication, etc. METAL PROGRESS anticipates their needs. They learn from it . . . depend on it . . . contribute to it. Reason enough that METAL PROGRESS is *also* your best advertising approach to this vital market in 1959.

Dr. Leiter heads an extensive staff of metals engineers. Here he inspects a forged and butt-welded compressor ring of a Pratt & Whitney Aircraft J57 turbojet engine with Chief Metallurgist Charles B. Allen (L) at Budd's Red Lion Plant.



Marjorie R. Hyslop
Managing Editor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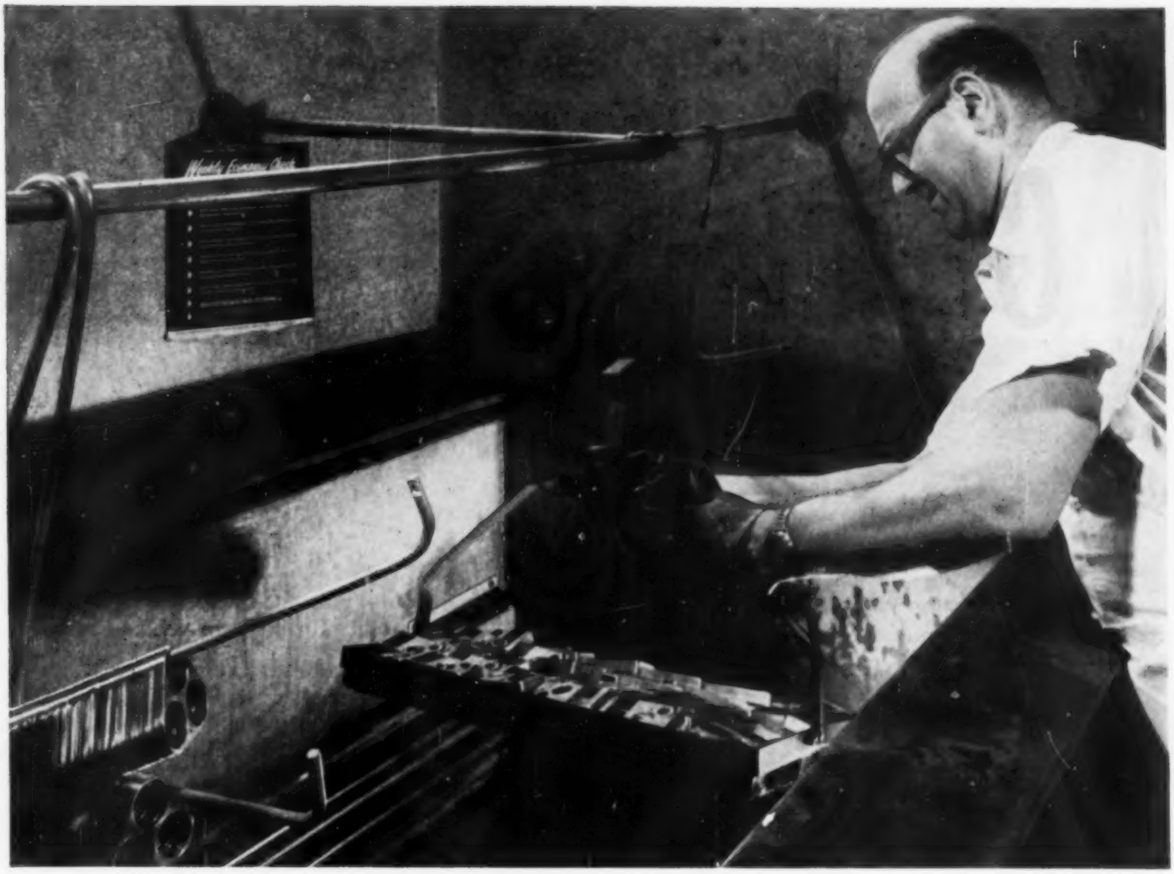
ONE SOLVENT –



TWO JOBS

Now you can use one grade of trichlor for both . . .
Nialk trichlor with **psp**

Now you take trichlor for missile flushing and vapor degreasing out of the same drum.

The *metal degreasing* grade of Nialk® trichlorethylene meets industrial specs for flushing missile and rocket components. Its residue count is a low 0.0005%. It meets impact sensitivity requirements.

Save storage space. You can cut inventory to the bone with this single grade of trichlor. The savings in time and money are obvious.

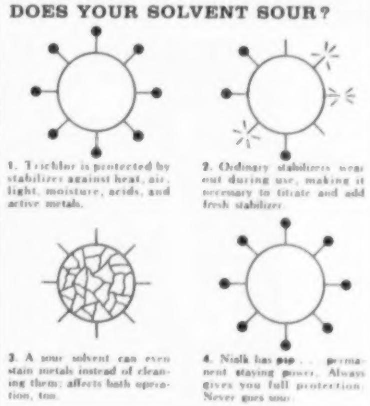
Eliminate mistakes. There's no chance of picking the wrong drum to do a job when you stock just one grade for all work.

No disposal problems. Take the same trichlor you use for flushing and you can use it in your vapor degreaser without distilling.

Get psp too. Get the extra advantages of **psp**—**p**ermanent **s**taying **p**ower—in your trichlor. See box at right for details.

Send for bulletin. Data Sheet 814 should answer any questions you have about Nialk trichlor. Write for a copy.

DOES YOUR SOLVENT SOUR?



1. Trichlor is protected by stabilizer against heat, air, light, moisture, acids, and active metals.

2. Ordinary stabilizers wear out during use, making it necessary to titrate and add fresh stabilizer.

3. A sour solvent can even stain metals instead of cleaning them; affects both operation, too.

4. Nialk has **psp** . . . permanent staying power. Always gives you full protection. Never goes sour.

HOOKER CHEMICAL CORPORATION

403 UNION STREET, NIAGARA FALLS, N. Y.

Sales Offices: Chicago, Detroit, Los Angeles, New York, Niagara Falls, Philadelphia, Tacoma, Worcester, Mass.

HOOKER CHEMICALS PLASTICS

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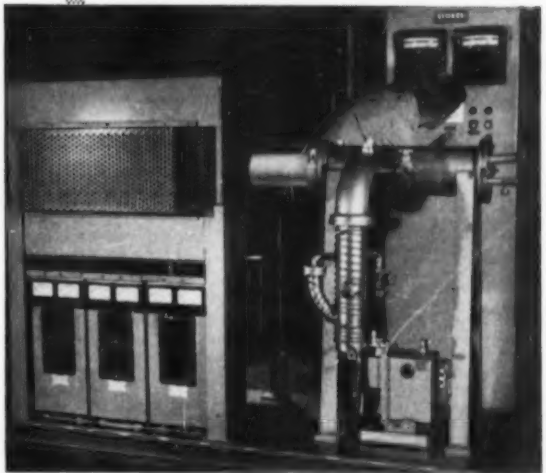
Progress...

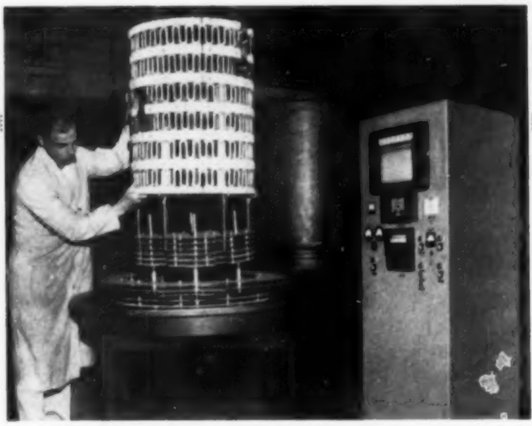
Furnaces



production size systems. Other types are available for melting, refining, casting, sintering, brazing and stream degassing. Special systems can be designed to meet the exact needs of specific operations. All-the-way service, before and after the sale, completes the picture of how well Stokes is equipped to work with you.

You can take full advantage of Stokes' advanced vacuum technology. The Stokes Engineering Advisory Service will assist you in planning and designing a heat treating installation that will best serve your exact requirements. Call Stokes—today.

A resistance-heated, two-zone, high temperature Vacuum Heat-Treat Furnace . . . installed for operation over 2500°F. Available in sizes to 9" I.D., for brazing, out-gassing and heat-treating . . . in both research investigations and small parts production.



A cold wall furnace capable of providing high temperatures at unusually low pressures is one of the most recent developments of Stokes. It is particularly applicable to high temperature solid state processing. Depending on the nature of the application, temperatures up to 2000°C are attainable at sub-micron pressure. Customer built for specific requirements, these furnaces are offered in a wide range of sizes, for research or production service.

In addition, Stokes offers complete laboratory facilities and technical assistance for investigation of commercial heat treating applications where highest temperatures are necessary.

Vacuum Equipment Division
F. J. STOKES CORPORATION
5500 Tabor Road, Philadelphia 20, Pa.

STOKES

WILSON "ROCKWELL"
HARDNESS TESTERS • *WORLD'S STANDARD OF ACCURACY*

ACCO for Better Values

Equipment for *EVERY Hardness Testing Requirement*

WILSON "ROCKWELL" HARDNESS TESTERS ...ACCURATE AS A PRECISION BALANCE

No matter what your hardness testing requirements are, there's a WILSON "ROCKWELL" instrument to do the job. Choose from this complete selection of hardness testers:
"ROCKWELL"—for most hardness testing functions.
Superficial—for extremely shallow indentations.
Twintester—combines functions of "ROCKWELL" and "ROCKWELL" Superficial testers.
Semi-Automatic (manual feed) and Fully Automatic—for automatically classifying tested pieces as CORRECT, TOO HARD, or TOO SOFT—at test rates up to 1000 pieces per hour.
Special Machines—for testing large objects, obtaining internal readings, and other unusual applications.

ALL WILSON "ROCKWELL" hardness testers provide these advantages:
Accurate performance—precision built, with exact calibration, for consistently correct results.
Long life—durable as a machine tool.
Easy operation—even an unskilled operator can get perfect readings. All controls conveniently grouped.
Easy maintenance—interchangeable mechanisms, with spindles mounted on oil-less bearings.

DIAMOND "BRALE" PENETRATORS... perfect testing every time

A perfect diamond penetrator is essential to accurate hardness testing. Since one point of hardness on the "ROCKWELL" scale represents only 80 millionths of an inch penetration—only 40 millionths on a Superficial tester—the slightest imperfection will cause a false reading.

Only *perfect* Wilson Diamond Brale Penetrators are sold. Each diamond is flawless, with no chips or cracks. It's cut to an exact shape. Microscopic inspection of every diamond—one at a time—assures this perfection—and assures you of accurate hardness testing every time.

TUKON TESTER ... for precision MICRO & MACRO testing

The TUKON Tester measures extremely shallow indentations. It's used, for instance, by manufacturers of watches, hairsprings, needles, and fine wire. Laboratories use the TUKON for tests on individual crystals or particles of microscopic size. Producers of coatings, film, ceramics, and many other materials have made good use of the TUKON.

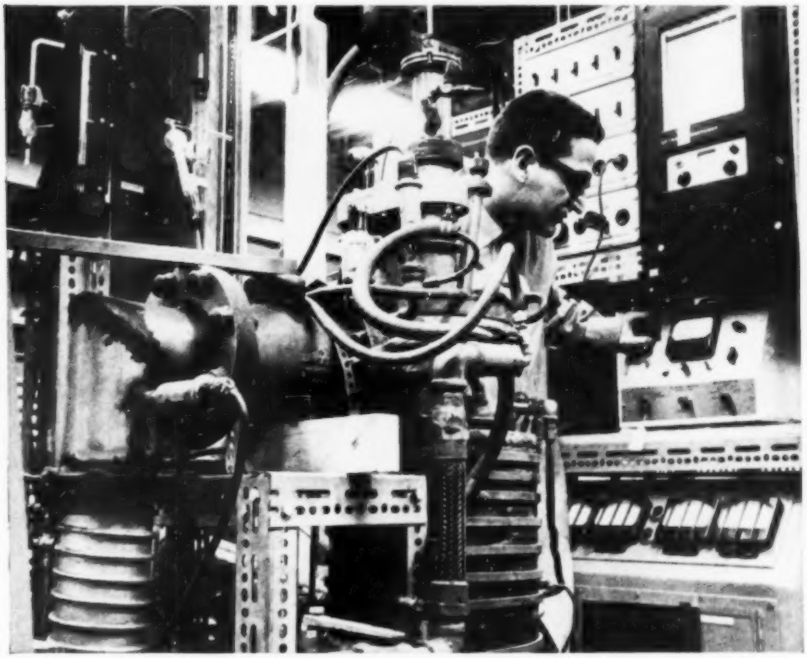
Three models are available to meet your individual requirements. TUKON Testers use both the Knoop and 136° Diamond Pyramid Indenter. Each TUKON Tester is a self-contained hardness testing instrument— no accessory equipment is needed. Knife edges and levers of fixed length are used throughout for application of exact load and freedom from internal friction.

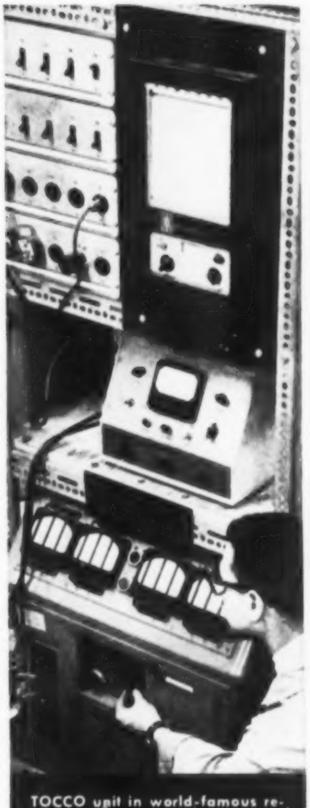
A COMPLETE LIBRARY of helpful information

A wide variety of bulletins describes the many instruments, accessories, and services Wilson offers. Write for your choice:
DH-325 — WILSON "ROCKWELL" Hardness Testers • **DH-326** — "ROCKWELL" Superficial Hardness Testers • **DH-327** — Special "ROCKWELL" Testers, including Automatic and Semi-Automatic models • **DH-7** — TUKON Applications • **DH-328** — TUKON Testers.

ACCO **WILSON**
MECHANICAL INSTRUMENT DIVISION
AMERICAN CHAIN & CABLE
230-F Park Avenue, New York 17, N.Y.

ideal climate for a hot idea . . .





TOCCO unit in world-famous research laboratory, currently engaged in studying the solubility of nitrogen in molten metals.

3000°F. . . . ± 2°F. . . .

with TOCCO Induction Heating*

Heart of this complex looking laboratory setup is a 15 kw, 10,000 cycle TOCCO Induction Heating unit. More and more research laboratories, in industry and in educational and research institutions are finding TOCCO the ideal high temperature source. Many TOCCO units are today in use not only in metallurgical experimentation but in high temperature chemistry and solid state studies.

TOCCO's advantages for use in research laboratories include:

- complete lack of radiant heat and gases
- clean and compact—only about four square feet of floor space required
- extremely accurate temperature control
- whisper-quiet operation
- extreme versatility
- ideal for heating in vacuum or controlled atmosphere

Whether you're interested in a production workhorse or a laboratory tool, it will pay you to investigate TOCCO induction equipment as a fast, efficient and accurate method for heating ferrous and non-ferrous metals.

JUST PUSH A BUTTON

TOCCO

*Trade Mark Reg. U.S. Pat. Off.

THE OHIO CRANKSHAFT COMPANY

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The Ohio Crankshaft Co. • Dept. R-3, Cleveland 5, Ohio

Please send copy of "Typical Results of TOCCO Induction Heating — Principles, Applications, Equipment."

Name________________

Position________________

Company________________

Address________________

City________ Zone____ State____

Memo on Metals

New Age-hardenable Titanium Alloys Offer Up to 220,000 psi Tensile Strength and Easier Formability for 600 to 1,000 F Applications

Three new age-hardenable titanium alloys may prove to be the solution to many of the strength-weight and temperature problems encountered in designing advanced aircraft and missiles. They may also prove extremely economical for such applications.

All three offer much higher strengths than other titanium alloys – and have the light weight and corrosion resistance typical of titanium alloys. Furthermore, they are readily FORMAGEABLE* – capable of being formed in the solution-treated or "soft" condition and then strengthened by simple thermal aging techniques. Each is now in pilot production and available in limited quantities of mill products.

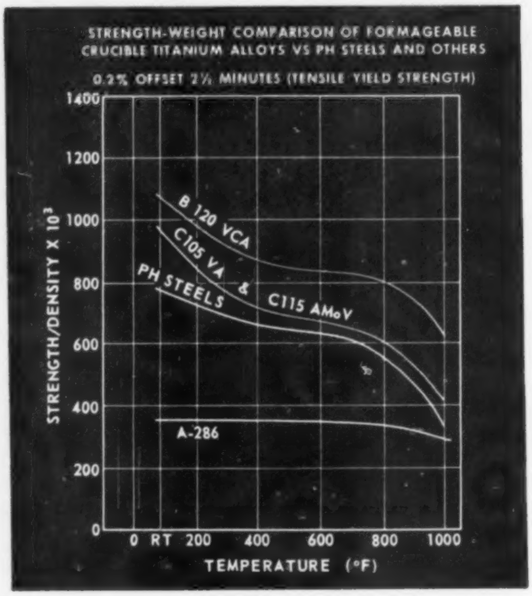
First Age-hardenable All-beta Ti Alloy

Crucible B-120VCA is the first useful titanium alloy with an all-beta (high temperature) structure. It has both the highest strength and best formability of any titanium-base alloy.

This alloy's composition (13%V-11%Cr-3%Al) enables its structure to stay all-beta during forming and/or during slow cooling, and to age to high strength levels at temperatures where distortion is not a problem.

B-120VCA has a unique combination of properties. Room temperature strengths of 200,000 to 250,000 psi have been obtained. On a strength-weight basis this is the highest strength of any available structural material. In short-time elevated temperature tensile tests (1-2 minutes), it offers a decided strength-weight advantage over alternate materials at temperatures up to at least 1,000 F. Under creep conditions, for very long periods of time, it enjoys a strength-weight advantage up to at least 600 F. Beyond this limit, the other Crucible FORMAGEABLE titanium alloys are recommended.

B-120VCA is ductile-weldable, cold-headable, and has great and deep hardenability. Because of this formability, it should prove suitable for applications such as aircraft skins, stiffeners and other primary structural shapes, and for missile pressure tanks, rocket motor cases and structural members. Preliminary tests indicate it may prove unequalled as a construction material for honeycomb assemblies. Because

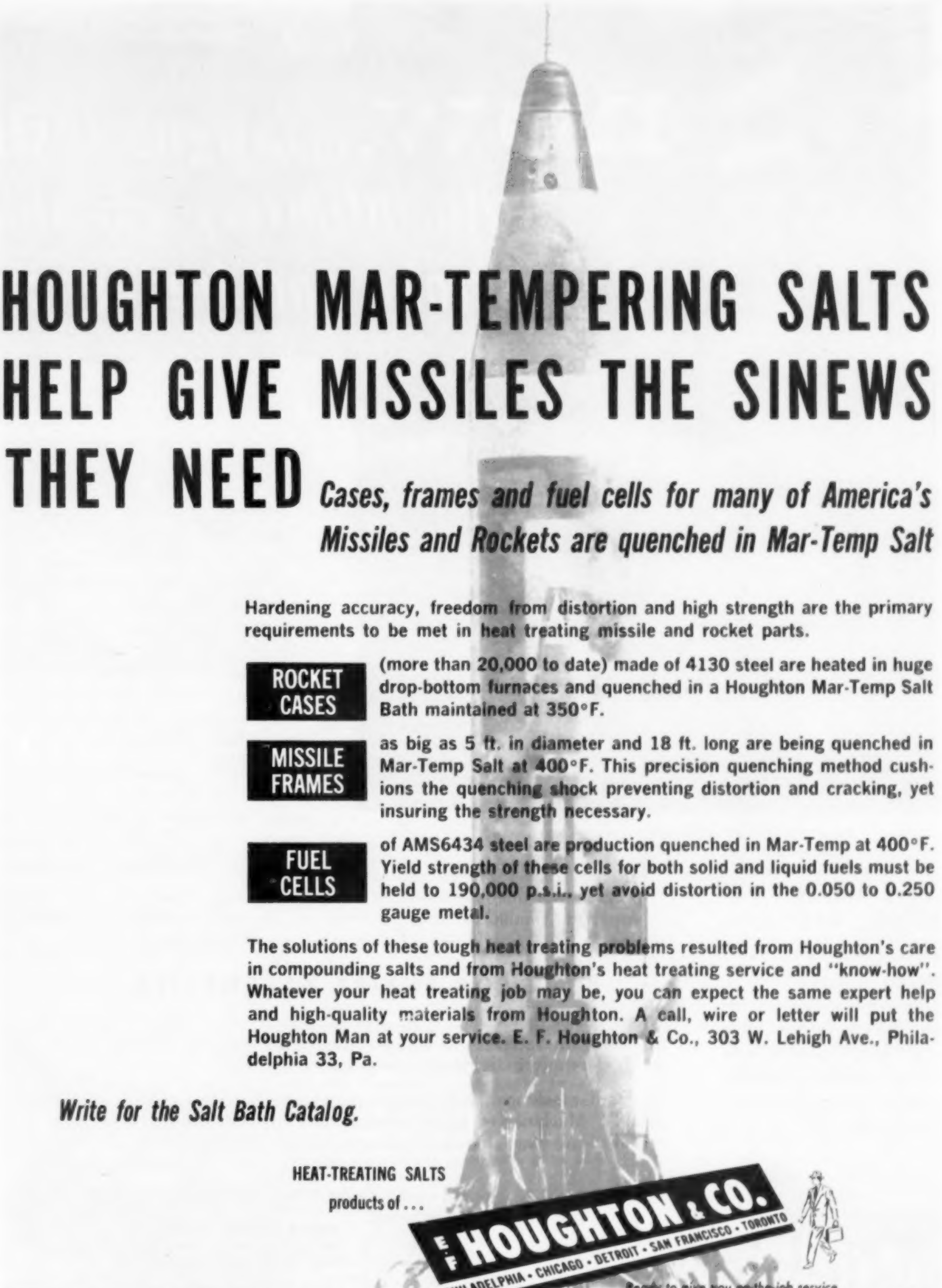


it is so easy to cold-head, it has a large potential in such items as rivets.

Alpha-beta Titanium-base Alloys

Crucible C-105VA is an alph-beta titanium-base material which also is FORMAGEABLE. Its 16% vanadium content stabilizes a sufficient amount of the beta phase for good age-hardenable response; the 2.5% Al content improves the alloy's elevated temperature properties.

C-105VA resolves two conflicting requirements for aircraft sheet material. It is soft, ductile and easily formed in the solution-quenched condition. Because the formed parts can be aged subsequently at moderate temperatures, parts made of C-105VA can possess high strengths at temperatures up to 800 F for long periods of time.



APPLICATION and EQUIPMENT new products

Salt Bath

A 3-in-1 salt-bath furnace for limited production of high-speed tool steels has been announced by the A. F. Holden Co. It consists of three pot units: (1) a gas-fired alloy pot for hardening and preheating any type

high-speed steel at 1300 to 1800° F.; (2) a two-electrode ceramic pot with temperature range of 1750 to 2350° F. for treating high-carbon high-chromium and air-hardening steels; (3) a pressed steel pot for quenching at heat levels from 1000 to 1450° F. All are neutral salt baths.

For further information circle No. 402 on literature request card, page 48-D.

Conductivity Meter

Magnaflux Corp. has announced a conductivity meter which provides immediate reading of conductivity, calibrated in absolute units. It can

be used for measurements based upon the relationship between electrical conductivity and other properties of nonmagnetic metals such as evaluating alloy, hardness, uniformity of heat treatment and sorting of mixed nonmagnetic metals. The FM-110 is powered by two flashlight batteries and therefore can be used anywhere.

For further information circle No. 403 on literature request card, page 48-D.

Hard Facing

Crucible Steel Co. has announced a new hard facing alloy for hot work applications. Rexweld 66 is a cast nickel-chromium-molybdenum-tungsten alloy which may be used with inert gas arc or metal arc welding. Electrodes are coated with a low-hydrogen coating, permitting all-position welding.

For further information circle No. 404 on literature request card, page 48-D.

Foamed Metal

Foamed metal that resembles a petrified sponge and is nine times lighter than solid metal has been announced by General Electric Co.'s Flight Propulsion Laboratory. It is made by pouring mixed ingredients into a mold and baking. The rising or foaming action takes place early in the baking process. Although the technique is still in the development stage, nickel, copper and cast iron have been successfully foamed. The weight and strength of foamed metals are in proportion to their density, which can be controlled. Suggested applications are for jet engine parts, and foamed copper might be used in electrical installations because of its natural cooling property.

For further information circle No. 405 on literature request card, page 48-D.

Blast Cleaning

A new 6-ft. Rotoblast table-room for cleaning all types of work has been announced by the Pangborn Corp. Capable of blast cleaning castings, forgings and stampings up to 72 in. in diameter by 36 in. high, and weighing up to 5000 lb., this new table is equipped with a cast labyrinth abrasive sealing system which makes the cabinet abrasive-tight without rubber gaskets. An overhead blast wheel, powered by a 30 hp. motor, will throw 50,000 lb. of abrasive per

hour. A new safety feature is power-operated guard plates that are positioned in front of the Rotoblast wheel when the motor is turned off to prevent abrasive from striking the table. When the abrasive wheel is turned on again, the guard plates retract to their original position.

For further information circle No. 406 on literature request card, page 48-D.

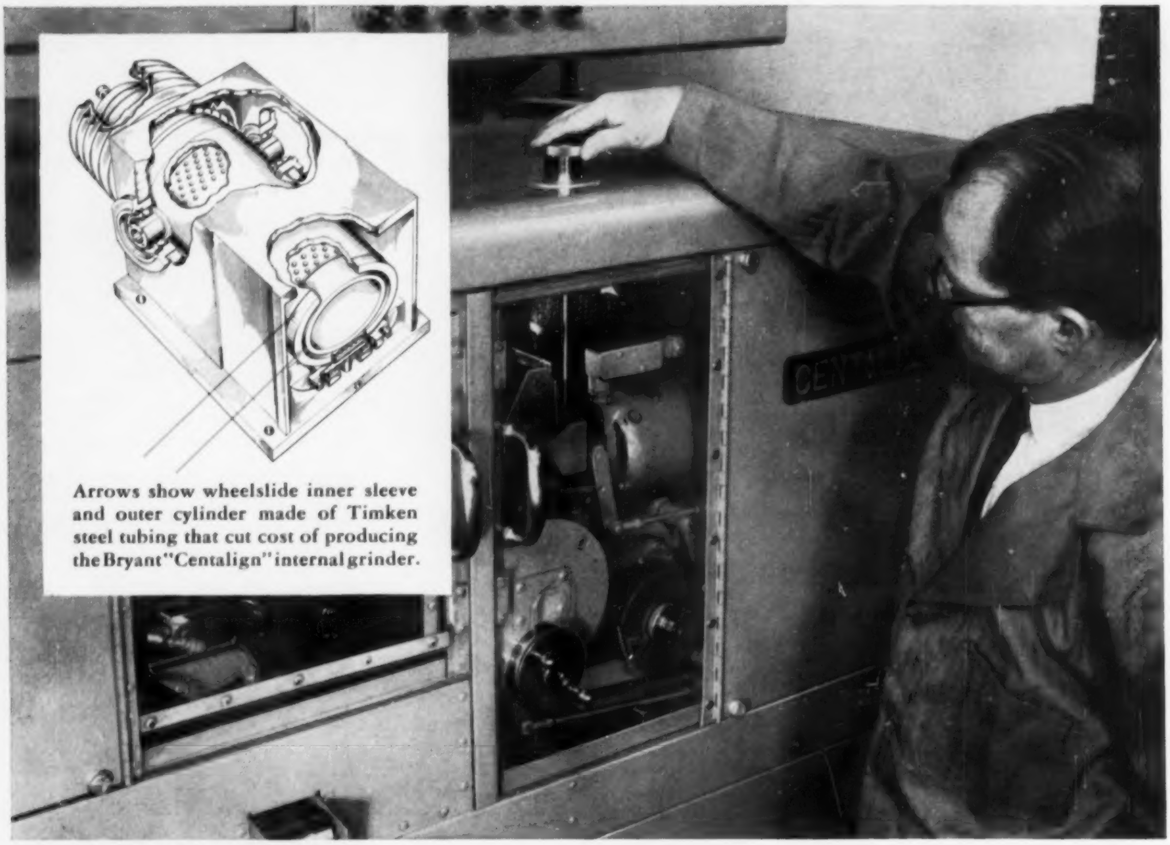
Refractory Brick

Refractories Div., H. K. Porter Co., has announced a new refractory brick, Multex-85. The high-alumina brick was developed for the aluminum industry. Advantages claimed are: (1) molten aluminum will not penetrate it; (2) silicon pick-up is reduced; (3) the tendency of drosses and fluxes to adhere to sidewalls is reduced, allowing easier cleaning of furnaces. Multex-85 is available in all standard sizes and shapes.

For further information circle No. 407 on literature request card, page 48-D.

Induction Melting

A console panel containing the power source, controls and all components necessary to the operation of high-frequency induction furnaces



Arrows show wheelslide inner sleeve and outer cylinder made of Timken steel tubing that cut cost of producing the Bryant "Centalign" internal grinder.

BRYANT CHUCKING GRINDER CO.

Saves 45% with switch to TIMKEN® steel tubing

ENGINEERS at Bryant Chucking Grinder Co. wanted to reduce the cost of producing this "Centalign" internal grinder. They blamed high costs on spoilage due to weld checking and excessive machining time of the inner sleeve and outer cylinder of the wheelslide. When they consulted Timken Company metallurgists, these experts studied all angles of the problem. And they recommended a change to a certain grade and size of Timken® seamless steel tubing. Here's what happened.

Because the tubing was perfectly suited to welding, checking was ended. And costly machining time was cut because excessive stock removal was eliminated. The tubing was the right size for the job. They cut production costs 45%! What's more, the tubing had the desired hardness and grinding properties, responded uniformly to heat treatment.

Timken seamless steel tubing gives better quality finished products because of the way we make it. We forge a solid round over a mandrel, thoroughly working the metal inside and out. This rotary piercing operation gives the tubing its fine forged quality and uniform spiral grain flow for extra strength. Careful control keeps this quality uniform from tube to tube, heat to heat, bar to bar.

To help cut costs on your hollow parts jobs, let our engineers recommend the tube size most economical for you. It's guaranteed to clean up to your finished dimensions. The Timken Roller Bearing Company, Steel and Tube Division, Canton 6, Ohio. Cable: "TIMROSCO". Makers of tapered roller bearings, fine alloy steels and removable rock bits.

Timken alloy steel and seamless tubing is available from warehouse stock in 44 cities in the United States. Call your local Timken Company sales office for the name of your nearest Timken steel distributor.

TIMKEN® *Fine Alloy* STEEL

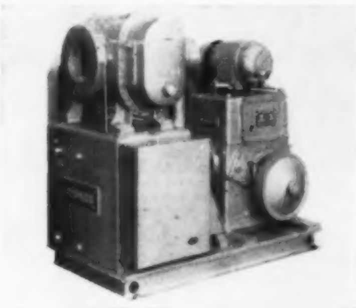
SPECIALISTS IN FINE ALLOY STEELS, GRAPHITIC TOOL STEELS AND SEAMLESS STEEL TUBING

and coils has been announced by Inductotherm Corp. It features a 30 kw. motor-generator set, a high-frequency transformer, capacitors, meters and controls. The unit is installed by connecting it to a 220 or 440 volt power supply, a cold water line and a drain. Furnaces or coils are connected to the unit by leads which supply both power and cooling water. The unit is made portable by mounting it on casters. It can then be used wherever the necessary power and water are available.

For further information circle No. 408 on literature request card, page 48-D.

Vacuum Pumps

A new series of mechanical booster vacuum pumps has been announced by the Vacuum Equipment Div. of F. J. Stokes Corp. The Model 1710,



shown above has a maximum pumping speed of 1050 cfm. and is capable of an ultimate vacuum below 1/2 micron. Other units in the new series have maximum pumping speeds of 1250, 2900, and 5100 cfm. These pumps are integrated two-stage pumping systems, built on a common base plate. First stage is a Roots-type dry blower that acts as a supercharger for the second stage, a standard gas-ballasted rotary vacuum pump.

For further information circle No. 409 on literature request card, page 48-D.

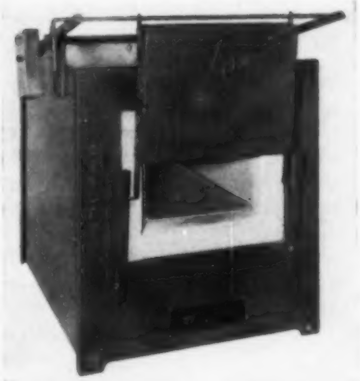
Stainless Steel

The Carpenter Steel Co. has announced commercial availability of Type 304L stainless steel containing 2% boron. It is melted in electric arc furnaces with melt capacities of 12 to 14 tons, whereas previously, the material had to be melted in vacuum furnaces which limited the size of the melt to under 4000 lb. The alloy is being produced in two rectangular shapes—6 by ⅜ and 3 by ⅜ in.

For further information circle No. 410 on literature request card, page 48-D.

Heat Treating Furnaces

Cooley Electric Mfg. Corp. has announced two new electric furnaces



for production heat treating in the temperature range of 300 to 2000° F. Chamber dimensions are 10 by 7 by 18 in. and 8 by 6 by 14 in. The new furnaces feature multislab insulation and have heavy sheet steel bodies and cast iron end frames. Heating elements are embedded. Hearth plate is of cast nickel-chromium alloy.

For further information circle No. 411 on literature request card, page 48-D.

Spray Painting

Equipment for airless spray painting will be exhibited at the Western Metal Congress and Exposition, March 16 to 20, by Nordson Corp. Spray guns are manual or automatic, and portable or stationary, as de-

sired. No spray booth is necessary and overspray is slight due to elimination of air as an atomizing agent.

For further information circle No. 412 on literature request card, page 48-D.

Metal Sorting

J. W. Dice Co. has announced a new model Cyclograph for nondestructive testing and sorting of accidentally mixed or incorrectly processed metal parts. The instrument can be used on either ferrous or nonferrous metals and will sort raw stock, semifinished, or finished parts by their metallurgical characteristics such as analysis, hardness, structure or case depth. A known and acceptable part is used as a standard in adjusting the instrument. The

ACHESON

dispersions digest

Reporting uses for

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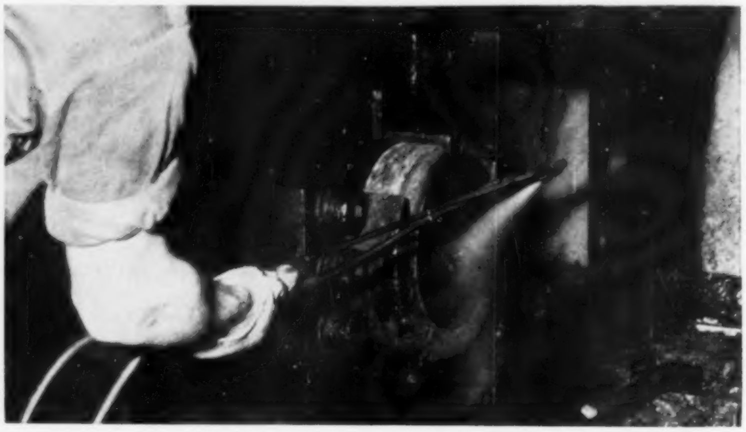
COLLOIDAL GRAPHITE, MOLY-SULFIDE, VERMICULITE, AND OTHER SOLIDS

WHY 'DAG' DISPERSIONS MEAN *PERFORMANCE* IN ALUMINUM EXTRUDING

The excellent lubricating properties of Acheson Colloidal Graphite, under conditions of extreme heat and pressure have been confirmed by leading extruders of aluminum, steel, copper, brass, lead and other metals. Water-base dispersions of colloidal graphite used in the following application histories have provided savings in material handling, reduced maintenance time and expense, prevented seizure, extended die life, and produced extrusions of more uniformly high quality. Any one of these benefits should make profitable reading for you.



For faster, more uniform application with less material consumption, Aluminum Extrusions, Inc. finds 'Aquadag' their best die lubricant.

A little 'Aquadag' goes a long way for Aluminum Extrusions, Inc., Charlotte, Michigan. This company, one of the leading independent extruders in the country, has found that by applying 'Aquadag' on die surfaces they have effected a 30% savings in their material handling. Formerly, they had used an oil-graphite mixture which required a dilution ratio of 16 lbs. of graphite to a 55 gallon drum of oil. It was too slowly applied by swab and too coarse to apply by spray with any degree of efficiency.

With 'Aquadag', Aluminum Extrusions has a lubricant that is finer in particle size, permits wider coverage, and provides greater "sprayability". These minute particles pass freely through the spray nozzle, eliminating the costly downtime formerly involved in cleaning clogged equipment. The tough, dry film 'Aquadag' forms upon the evaporation of its water carrier, doesn't smoke or react when applied to hot dies and metals. This improves working conditions as well as extends die life. Important also to both die surfaces as well as the finished extrusion, is the fact that this durable, low-friction film allows easier, more uniform metal flow.

Considered in relation to the over 12 million pounds of aluminum extruded yearly at this plant . . . 85% of it in fabricated form . . . *'Aquadag' has brought important production efficiencies and material economy* to Aluminum Extrusions, Inc. In many, similar instances where product quality and basic economy are demanded, Acheson colloidal dispersions have gained ready acceptance.

Exclusive Acheson processing techniques guarantee a consistently uniform top-quality product. If your problem is more effective lubrication under normally adverse conditions of extreme temperature, pressures, or abrasion, call in your Acheson Service Engineer.

Dies last three times longer with 'Aquadag', according to another prominent midwest extruder. Metal pickup on the extruding dies has been completely eliminated by the use of this Acheson dispersion, extending the effective use of the dies from 1000 to 3000 strokes. The evaporation of its water-base leaves a dry, adherent "graphoid" film on all lubricated surfaces, inhibiting the build-up of abrasive precipitates. At the same time, the unbroken, microscopically-thin film that 'Aquadag' provides, facilitates metal flow and reduces scoring to a negligible minimum. Application of the lubricant is by spraying a dilution of 1 part 'Aquadag' to 20 parts water, on the die surface before each "push" of the extrusion press.

A 'dag' graphite coating is also applied to the follow blocks on this company's 1400 ton horizontal extrusion presses. For purposes of even greater economy, 'Prodag' — semi-colloidal graphite in water — is used in this application. This effective parting agent prevents the flash, back-extruded from the billet skin, from locking the butt to the follow block. An Acheson dispersion is very possibly the answer to your lubricating troubles. For additional information, write for your free copy of Bulletin 426. Address Dept. MP 39.

Extended die life and extrusions with more perfect surface finish, are attributed to the use of 'Aquadag'.

ACHESON *Colloids Company*

PORT HURON, MICHIGAN

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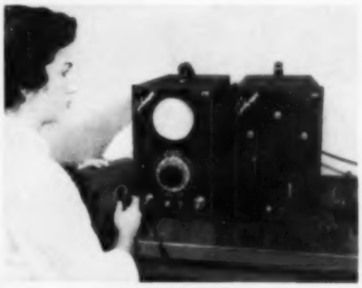
Model C-2 Cyclograph can be used as a hand sorter or it can be used in conjunction with an automatic relay unit which sends out a reject signal



whenever an off-standard part passes through the test coil. This signal can be used to activate a solenoid operated reject gate, paint spray marking device or other reject means.

For further information circle No. 413 on literature request card, page 48-D.

Resistance Heating

The Herscott Co. has announced a line of portable electric resistance heaters which may be used in wire-drawing, extruding, forging and other forming, drawing, rolling and heat treating operations. Units con-

sist of a resistance heater, temperature sensing head and recording controller. Standard units are 5, 10, 20, 30, 50 and 100 kw. and specials over 100 kw. The model shown is furnished in 5, 10 and 20 kw. and is 32 in. wide by 38 in. high by 24 in. deep.

For further information circle No. 414 on literature request card, p. 48-D.

Pickle

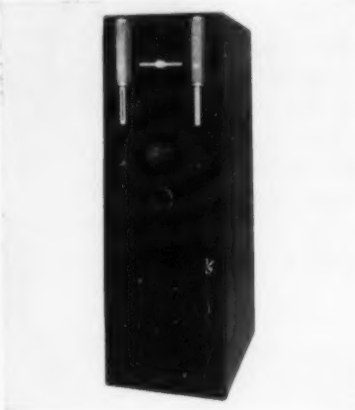
A new dry mixture that pickles all base metals and also strips chromium has been announced by Hanson-Van Winkle-Munning Co. The mixture includes acid salts, activators and surface active agents. For pickling, a solution is made by using from 4 to 32 oz. of Pickelene per gallon of water. For stripping chromium, a stronger concentration — 1 to 2 lb. per gallon — is recommended. Most operations employing Pickelene 300 can be performed in

lead, Koroseal, or rubber tanks, but lead is recommended if operating temperature is to exceed 180° F.

For further information circle No. 415 on literature request card, page 48-D.

Atmosphere Generator

A new gas generator has been announced by C. I. Hayes, Inc. The Nitro-Form produces 75 to 100% nitrogen atmosphere with 0 to 25% hydrogen, at minimum dew point.



Gas is saturated at 10° above cooling water. The unit is 2 by 3 by 6 ft. in size and requires only a few connections to put it into operation.

For further information circle No. 416 on literature request card, page 48-D.

Vacuum Pump

Rochester Div. of Consolidated Electrodynamics Corp. has announced the addition of a fractionating oil-diffusion pump with an internal casing diameter of 2 in. to its standard line of high-vacuum pumps. Since it is air cooled, it can be moved from place to place as long as electrical connections are available. A new baffle has been added to reduce vapor back-streaming. With the baffle in place, the new pump has a minimum speed of 40 liters per sec. in the 2×10^{-6} to 7×10^{-3} mm. Hg range, with a peak speed of 48 liters per sec. at 5×10^{-4} mm. Hg.

For further information circle No. 417 on literature request card, page 48-D.

Phosphate Treatment

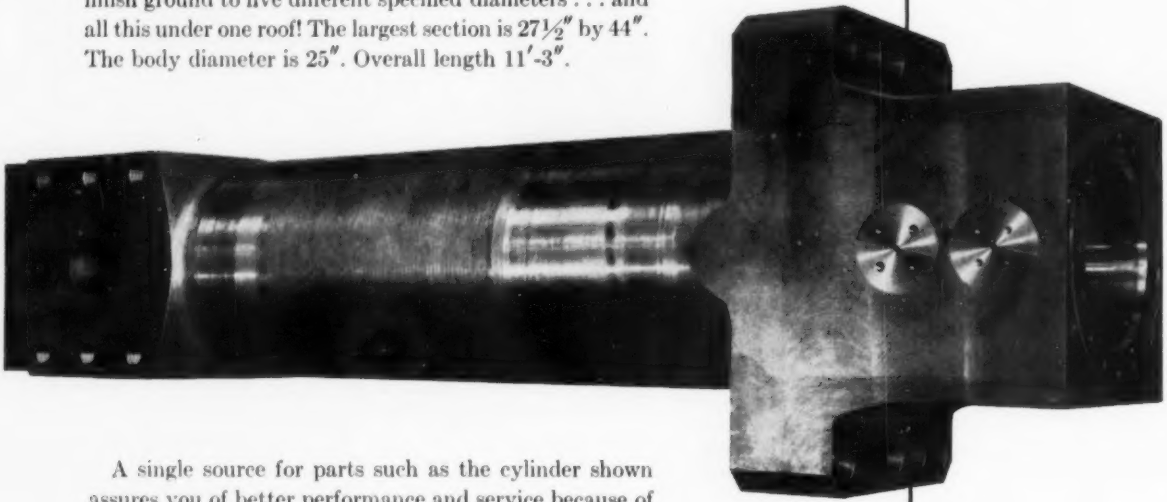
Cowles Chemical Co. has announced a new chemical which cleans the surface of the metal and produces an amorphous iron phosphate coating on ferrous metals, zinc and cadmium. Coatings weighing up to 60 mg. per sq. ft. provide a base for paint adhesion and corrosion protection. The new chemical is a granular powder.

For further information circle No. 418 on literature request card, page 48-D.

"Forgings by Finkl"

. . . from blueprint to finished part

This is a side cylinder for a hydraulic press. It was made from a Finkl C 1035 electric furnace steel forging weighing 32,000 pounds. When shipped it weighed 14,850 pounds. Between the start and finish it had been heat treated, milled, turned, tapped, and the inside bored and finish ground to five different specified diameters . . . and all this under one roof! The largest section is 27½″ by 44″. The body diameter is 25″. Overall length 11′-3″.



A single source for parts such as the cylinder shown assures you of better performance and service because of greater quality control through each step of its processing.

"Forgings by Finkl" is synonymous with highest quality. Finkl custom forgings have the stamina and fatigue resistance to withstand the severe strains and torsional stresses encountered in modern heavy duty machinery. We also produce repair parts for all types of forging equipment; containers, liners, and plungers for extrusion presses; plastic molds; and die casting steels.

Next time you are thinking of forgings, think of Finkl. The best costs the least in the long run.

DIE BLOCKS · FORGINGS · HOT WORK STEELS · ELECTRIC FURNACE STEELS

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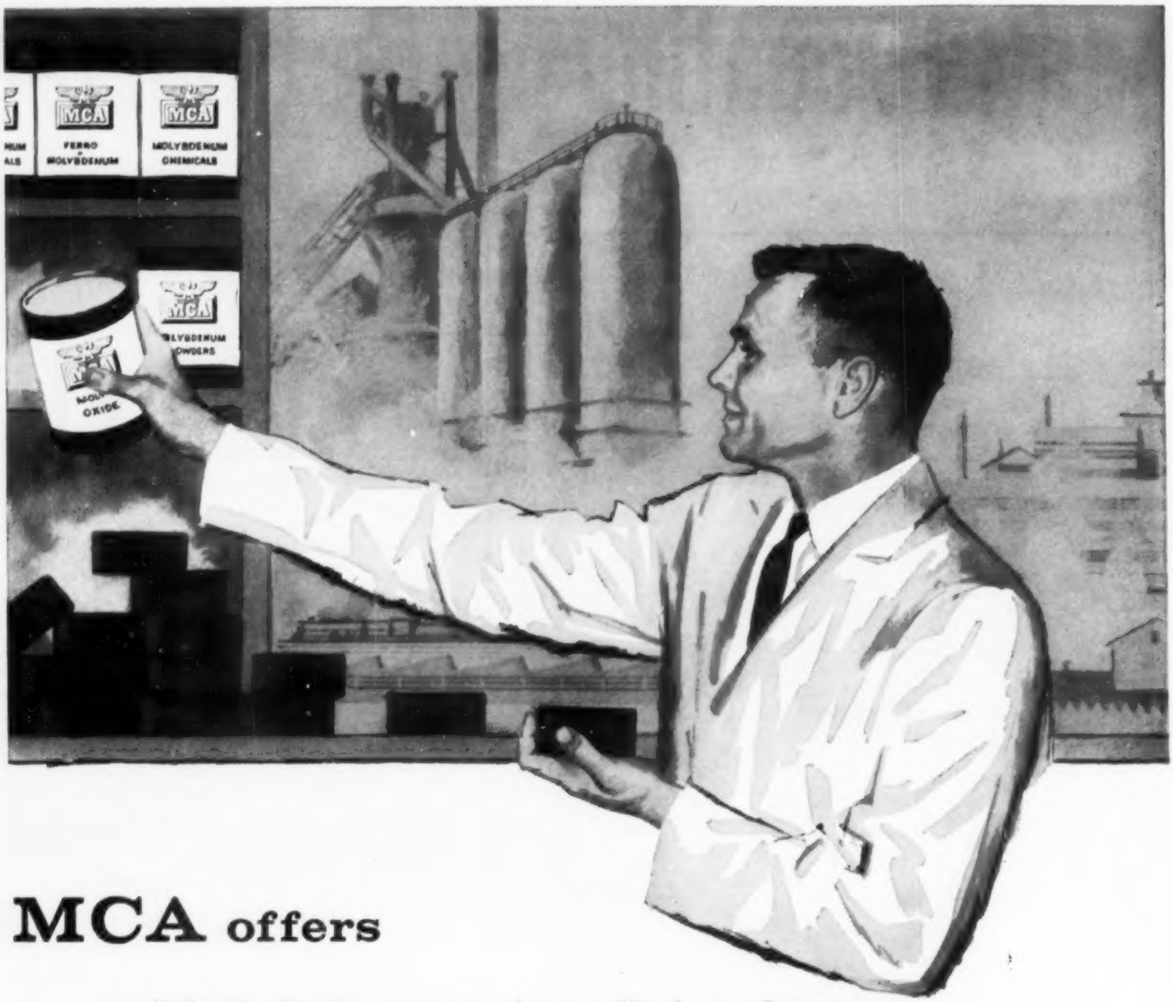

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Molybdenum in all its forms

Molybdenum is widely accepted in the iron and steel industry, because it imparts improvements in physical properties at costs that may be economically justified. Such properties are effective both in economy of production and user benefits. In high speed steels, automotive steels, in aircraft and missile steels, molybdenum by MCA performs to meet designer's requirements.

This expanding use of molybdenum has resulted in demand for various forms—chemicals, metal powder, metallic molybdenum and molybdenum oxide. MCA offers molybdenum in all commercial forms for easy and practical application in the mill. In addition, MCA's technical knowledge is unsurpassed and is available to the iron and steel maker upon request, free of charge.

When you have a metallurgy problem that molybdenum might solve, think first of MCA. When you need molybdenum in any form or quantity, MCA has it available for your use in iron and steel improvement.

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HANDY ALLOY DATA SHEET

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ALLOY LIST

Handy & Harman Silver Brazing Alloys

...The COMPLETE line that meets all specifications and production needs

Need to join any combinations of metals—ferrous and nonferrous? Investigate the vast number of products, assemblies and parts that are being joined better by silver brazing alloys. Handy & Harman, the Number One Source of, and Authority On Brazing Alloys and Methods makes—and makes readily available—the following silver brazing alloys:

HANDY & HARMAN SILVER BRAZING ALLOYS

NAME		SILVER	COPPER	ZINC	OTHER	MELTING POINT °F	FLOW POINT °F	TROY OUNCES PER CU. IN.
EASY-FLO		50%	15½%	16½%	(18% Cd.)	1160	1175	5.00
EASY-FLO #3		50	15½	15½	(16% Cd. 3% Ni.)	1170	1270	5.00
EASY-FLO 45		45	15	16	(24% Cd.)	1125	1145	4.92
EASY-FLO 35		35	26	21	(18% Cd.)	1125	1295	4.90
SIL-FOS		15	80	—	(5% P.)	1185	1300	4.45
SIL-FOS 5		5	88.75	—	(6.25% P.)	1185	1300	4.37
NEW NAME	**FORMER NAME**	**SILVER**	**COPPER**	**ZINC**		**MELTING POINT °F**	**FLOW POINT °F**	**TROY OUNCES PER CU. IN.**
BRAZE TEC*	TEC*	5	—	—	(95% Cd.)	640	740	4.60
" 056*	TEC-Z*	5	—	16.6	(78.4% Cd.)	480	600	4.53
" 071	SN #7	7	85	—	(8% Sn.)	1225	1805	4.82
" TL	TL	9	53	38		1410	1565	4.50
" 202	AT SPECIAL	20	45	35		1315	1500	4.68
" ATT	ATT	20	45	30	(5% Cd.)	1140	1500	4.64
" NE	NE	25	52½	22½		1250	1575	4.71
" 251	AE	25	57.5	17.5		1255	1625	4.68
" SS	SS	40	30	28	(2% Ni.)	1220	1435	4.76
" 404	SS-5	40	30	25	(5% Ni.)	1220	1580	4.72
" DT	DT	40	36	24		1235	1415	4.80
" DE	DE	45	30	25		1230	1370	4.82
" ETX	ETX	50	34	16		1250	1425	4.99
" 541	ALLOY-4772	54	40	5	(1% Ni.)	1340	1575	5.06
" 560	ER	56	22	17	(5% Sn.)	1145	1205	5.00
" 580	EB	57.5	32.5	—	(3% Mn.- 7% Sn.)	1120	1345	5.05
" RT	RT	60	25	15		1245	1325	5.02
" 603	RT-SN	60	30	—	(10% Sn.)	1115	1325	5.23
" 630	RSNI	63	28.5	—	(6% Sn.- 2.5% Ni.)	1275	1475	5.12
" EASY	EASY	65	20	15		1235	1325	5.06
" MEDIUM	MEDIUM	70	20	10		1275	1360	5.14
" BT	BT	72	28	—		1435	1435	5.24
" HARD	HARD	75	22	3		1365	1450	5.28
" 752	TR #1	75	—	25		1300	1330	5.06
" IT	IT	80	16	4		1345	1490	5.29
" 852	85 Ag.-15 Mn.	85	—	—	(15% Mn.)	1760	1780	5.08

*A Solder—Not a Brazing Alloy

Space does not permit listing the many special alloys, formulated for a particular or unique application. Handy & Harman Brazing Engineers and Technical Service are always ready to work closely with you on metal-joining problems and methods.

Comprehensive technical literature covering all aspects of brazing methods and alloys awaits your request.

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This informative booklet gives a good picture of silver brazing and its benefits...includes details on alloys, heating methods, joint design and production techniques. Write for your copy.

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From General Electric . . .
HEAT

G.E. DESIGNS NEW FURNACE FOR HIGH-TEMPERATURE VACUUM OPERATIONS

Versatile new radiation shield furnace breaks heat barriers of conventional furnaces for critical super-alloy heating jobs

These new General Electric radiation shield furnaces give you faster heating and cooling cycles than you can obtain with your present hot retort furnaces. But in addition, they offer unmatched versatility for your future heating needs which hot retort furnaces can't possibly handle.

G-E radiation shield furnaces have been designed to operate from 1900 F to 2600 F, and in smaller sizes up to 4200 F. They can be used with vacuum, or with inert or hydrogen atmospheres. They are readily adaptable for the heat treatment, brazing and sintering of super-alloy stainless steel, and metals like titanium and zirconium.

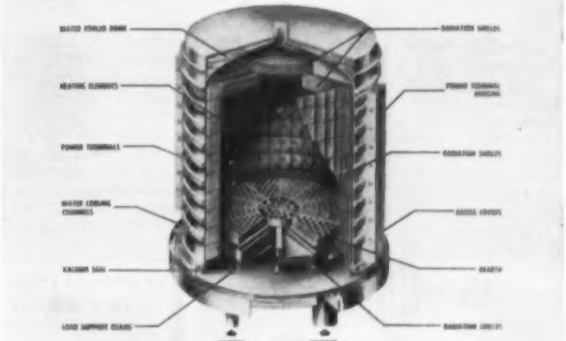
In addition to the versatility of higher temperatures and atmospheres, there's no metal retort between the heating units and the work in a radiation shield furnace. You get fast heating. And rapid cooling rates are provided by G.E.'s new cooling system that allows rapid recirculation of the cooling medium. Because of the more rapid heating and cooling cycles, a single radiation shield furnace can often do the work of a hot retort furnace with two bases and retorts . . . and give you substantial savings in floor space.

If you heat treat super alloys, seriously consider the advantages of a new G-E radiation shield furnace. You'll find General Electric engineers have the knowledge and design skill to match a furnace to your needs. Call your G-E Heating Specialist. Contact your nearby General Electric Apparatus Sales Office, or write Section 721-24, General Electric Company, Schenectady 5, New York.

GENERAL ELECTRIC

TYPICAL APPLICATIONS	Stress Relief	Annealing	Brazing	Sintering	Solution Heat Treatment	Degassing
Stainless Steels	x	x	x	x	x	x
Super Alloys	x	x	x	x	x	x
Tungsten	x	x	x	x	x	x
Tantalum	x	x	x	x	x	x
Molybdenum	x	x	x	x	x	x
Columbium (niobium)	x	x	x	x	x	x
Titanium	x	x	x	x	x	x
Vanadium	x	x	x	x	x	x
Zirconium	x	x	x	x	x	x
Hafnium	x	x	x	x	x	x

***High-temperature heat treating equipment** of all types, ranging from the box furnace at left to the radiation shield furnace at right, are available from General Electric.*



***The new radiation shield furnace** is another example of General Electric pioneering in the field of high-temperature heat treating. This furnace is rated from 1900 to 2600 F, in smaller sizes up to 4200 F.*

HIGH TEMPERATURE
VACUUM FURNACE

- ***Large 6" I.D. x 10" Heating Element***
- ***Automatic Protective Devices***
- ***Operates at 10^{-5} mm Hg or with Inert Gas***

Connect water, power, air and drains to the NRC Model 2915 and you're in business. That's just the first convenience you'll experience when you use this new refractory-free resistance furnace to sinter or heat treat reactive or high temperature metals and ceramics!

Loading, unloading, and cleaning are quick and easy. With one finger you can raise the spring-loaded stainless steel cover and lift out the top heat shield assembly. For cleaning, the heating element and other shield assemblies can be removed in less than 30 minutes. Every square inch of the stainless furnace chamber is accessible. Graphic control panel simplifies operation.

The three-phase cylindrical heating element offers long, trouble-free life because of its rugged construction, three point support, and ample spacing from heat shields.

This furnace will help you make more money. Large capacity, rapid heating and cooling, and high speed evacuation increase productivity. Double glass sight port, interlocked, fail-safe pumping system and power supply protect work and heating element against excess pressure and temperature. Special circuit prevents air-releasing before work is sufficiently cool.

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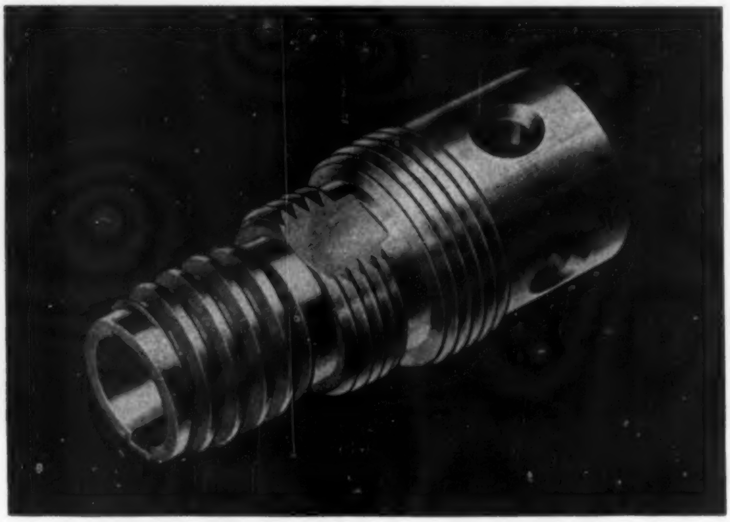
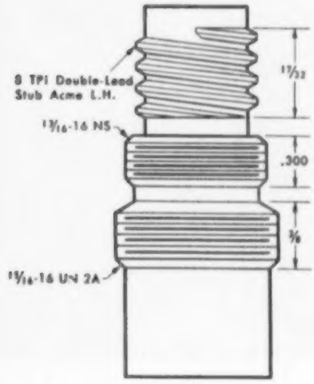
☐ *Please rush me data sheet on NRC Model 2915 Vacuum Resistance Furnace.*
☐ *Please have sales engineer call.*

NAME..TITLE..................
COMPANY..
STREET..
CITY, ZONE, and STATE.......................................

COST CUTTING on tough jobs–like rolling a double-lead Stub Acme thread–may be easier than you think. Olson Mfg. Co. needed only a minor adjustment in a standard Anaconda rod

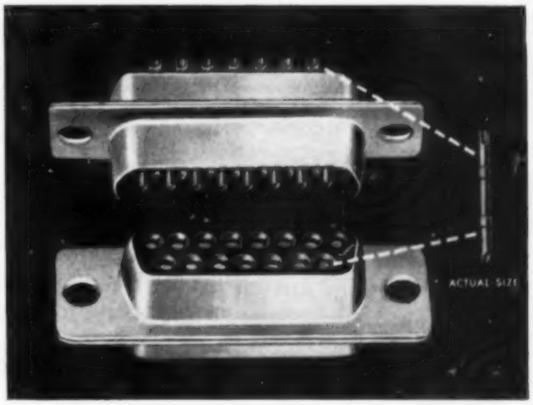


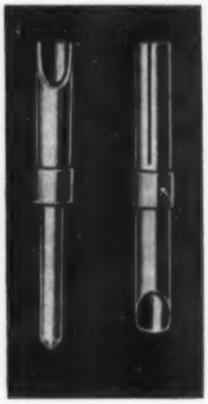


Rolling three threads *(drawing, right)* in two positions on a 6-spindle automatic meant cost savings for Olson Mfg. Co., Worcester, Mass. The Acme thread, however, posed problems. American Brass specialists suggested minor modification of standard Anaconda Free-Cutting Brass Rod to provide the extra ductility needed. The idea worked and the resulting valve spindle is shown above, about 1½ times actual size.

—or maybe you need a different alloy rod. The tiny connectors, right, have to be machined from .078" rod, requiring many precision form-cutting, drilling, slotting operations. So machinability is a vital property of the rod used—but so are adequate electrical conductivity, high strength, and fatigue resistance.

Cannon Electric, Los Angeles, makers of these electrical plug assemblies, had to find a rod with a delicately balanced combination of mechanical properties to provide the unfailing and continuous performance required. They found it in Anaconda Free-Cutting Phosphor Bronze-610 Rod, developed by American Brass metallurgists to combine the strength, resilience, fatigue resistance of phosphor bronze, and machinability approaching that of free-cutting brass.





MEETING the joint requirements of designers, manufacturing men, and buyers—to achieve high quality and performance while simplifying fabrication and cutting over-all costs—is an important function of American Brass technical specialists. For imaginative and practical help of this kind, see your American Brass Company representative or write: The American Brass Company, Waterbury 20, Conn. In Canada: Anaconda American Brass Ltd., New Toronto, Ont.

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APPLICATION and EQUIPMENT new literature

420. Abrasive Cleaning
Catalog 57-WX on brush types, sizes, speeds, filaments. Aids to power brush selection. *Pittsburgh Plate Glass*

421. Abrasive Cleaning
Folder on Malleabrasive for airless blast cleaning equipment gives advantages, grades, equipment it can be used with and parts that can be cleaned. *Globe Steel Abrasive*

422. Acids
Bulletin on naphthenic acids for emulsions and corrosion inhibitors. General properties, specifications. *Sun Oil Co.*

423. Air-Hardening Steel
New 8-page booklet gives composition, properties, elevated-temperature properties and heat treatment. *Latrobe Steel*

424. Alloy Castings
8-page bulletin on alloy castings for heat treating. *Ohio Steel Foundry*

425. Alloy Steel
14-page bulletin on two chromium-nickel alloy steels. Properties, working instructions, heat treatment, recommended uses. *Carpenter Steel*

426. Alloy Steel
12-page data sheet on Hy-Tuf alloy steel. Composition, properties, annealing. Hardenability band. TTT curves, bend tests for Hy-Tuf. *Crucible Steel Co.*

427. Alloy Steel
16-page book on type 9115 low-alloy high-strength steel. Properties, fabrication, welding. *Great Lakes Steel*

428. Alloy Steel
68-page "Aircraft Steels" includes revised military specifications. Also stock list. *Ryerson*

429. Alloy Steel Castings
Specifications for T-loy 34 and T-loy 42. Heat treatment and characteristics. *Unitcast Corp.*

430. Aluminum Bronze
8-page booklet on aluminum bronze bearing material which is forgeable, corrosion resistant, lightweight. *Mueller Brass*

431. Aluminum Die Castings
Bulletin on design and manufacture of aluminum die castings. *Hoover Co.*

432. Aluminum Extrusions
Folder lists alloys used, finishes, trade phraseology. *General Extrusions*

433. Aluminum Extrusions
Catalog of extrusion dies in stock. *Jarl Extrusions*

434. Aluminum Strip
20-page booklet on how it is made, sizes and weights of coils. Technical data on aluminum alloys used. *Scovill*

435. Ammonia
8-page booklet on uses of dissociated ammonia in industry. Dissociation process and applications in bright annealing, furnace brazing, powder metallurgy, bright hardening. *Armour Ammonia*

436. Annealing
New brochure describes and pictures precision annealing technique. Photomicrographs show grain structure. *Waterbury Rolling Mills, Inc.*

437. Atmosphere Equipment
New Bulletin No. I-101 on carbon dioxide removers. Design features, data chart, operation. *C. M. Kemp*

438. Atmosphere Furnace
New 12-page Bulletin 850.20 on controlled atmosphere reciprocating hearth furnace for continuous hardening, light case carburizing, Ni-Carb ammonia-gas carburizing and other heat treating processes. *American Gas Furnace*

439. Atmosphere Furnace
Bulletin on controlled atmosphere furnace. *Industrial Heating Equipment*

440. Atmosphere Furnace
Bulletins T-1090 and 1091 on atmosphere tube units give application, specifications, operation data. *Lindberg Engineering*

441. Atmosphere Furnace
12-page bulletin 1054 on electric furnaces with atmosphere control for hardening high speed steel. *Sentry*

442. Atmospheres
Chart recommends furnaces and atmospheres for annealing, brazing, carbonitriding, carburizing, enameling, hardening, normalizing, stress relieving. *C. I. Hayes*

443. Bolts
16-page booklet on high-strength bolting for structural joints includes ASTM specifications covering this bolting material. *Bethlehem Steel*

444. Brazing
8-page reprint on dip brazing aluminum assemblies. Design of parts, equipment used, maintenance, tooling. *Ajax Electric*

445. Carbon and Dew-Point Control
Bulletin DC-58 on Carbotronik and Dewtronik for control of carbon potential and dew point in atmospheres. *Ipsen*

446. Carbon and Graphite
Catalog Section S-5008 on carbon and graphite products for chemical operations includes heat exchangers, pumps, pipe and fittings. *National Carbon*

447. Carburizing
Data folder on Aerocarb E and W water-soluble compounds for liquid carburizing. Case depth vs. time curves. Per cent carbon and nitrogen penetration curves. *American Cyanamid*

448. Carburizing
Bulletin B-1 on process for pack carburizing steel in solid compounds. Charcoal-base and nonburning carburizers. *Park Chemical*

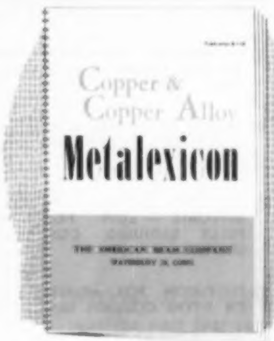
449. Castings
Literature on shell or sand castings of ArmaSteel, malleable iron or gray iron. *Central Foundry Div.*

450. Castings
New 8-page brochure on the centrifugal casting process. Illustrations describe applications and production. *Centrifugal Casting Co.*

451. Castings, Precision
4-page folder on small parts made by precision casting. Tolerances, alloys, configurations. *Casting Engineers, Inc.*

452. Centrifugal Castings
Folder on advantages of centrifugally cast thermalloy. *Electro-Alloys*

419. Copper Alloys
Terms used in the copper and copper-alloy industry are defined and illustrated in this 24-page Metalexicon. For instance, as a definition of Brass we find: "Any copper-base alloy with zinc as the principal alloying element, with or without small quantities of some other elements", while under Brasses, 46 different alloys from

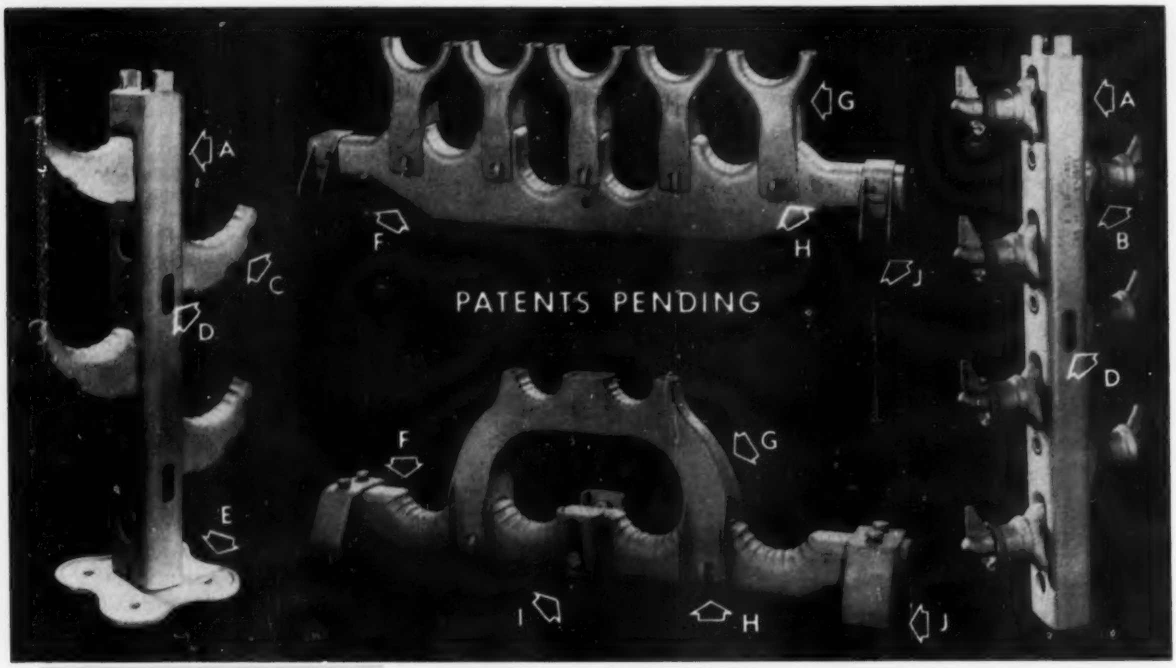


admiralty through yellow brass are described. Finished Edges is illustrated with drawings showing four types. Thirty-two different kinds of tubing are described and illustrated under Tube. Under Tube Measurement Terms are defined concentricity; diameter including average inside, average outside, at any point inside, at any point outside; roundness; wall thickness at any point and average. *American Brass Co.*

453. Chill Treatment
Case histories of experience in chilling metals at −130 to −150° F. for stabilization and controlled ductility. *Harris Refrigeration Co.*

454. Chromate Finishing
File on chromate conversion coatings for prevention of corrosion and paint-base treatment of nonferrous metals. *Allied Research Products*

455. Cleaning
Bulletin No. 72 gives reagents and pro-



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D PROVISION FOR HORIZONTAL OR X-TYPE COLUMN BRACES

E SEPARATE COLUMN BASES TO FACILITATE FIELD INSTALLATION

F TUBLARFORM BEAMS FOR STRENGTH AND PRACTICAL FIELD INSTALLATION

G INDIVIDUAL OR COMBINED UPPER TUBE SUPPORTS—AS NEEDED FOR SPECIFIC REQUIREMENTS

H SPECIAL PIN TYPE FASTENERS—WELDING IN ASSEMBLY MINIMIZED

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J CONNECTIONS TO FURNACE STRUCTURE—FUNCTIONAL AND EASY TO INSTALL

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cedure for acid acceptance test for trichlorethylene. *Hooker Chemical*

456. Cleaning
16-page manual on steam cleaner phosphating process. The value of phosphating, methods of application, application of steam cleaner method. *Malsbary Mfg. Co.*

457. Cleaning
44-page booklet, "Some Good Things to Know About Metal Cleaning", discusses tank, barrel and machine cleaning, pickling, zinc phosphate coating, rust prevention and other processes. *Oakite*

458. Cleaners
Folder on immersion, electrolytic, spray cleaners, phosphate coaters, strippers, drawing compounds, additive agents. *Northwest Chemical*

459. Coating Machine
New Bulletin FAC-200 on automatic conversion coating machine. Applications. *Hanson-Van Winkle-Munning*

460. Cold Rolling
Description of advantages of cold rolling of ship propeller shafting. How it is done. *Erie Forge & Steel*

461. Compressors
12-page Bulletin 126-B on application of turbocompressors to oil and gas-fired equipment used in heat treating, agitation, cooling, drying. Performance curves, capacities. *Spencer Turbine*

462. Controlled Atmospheres
Bulletin No. 2051 on Dewpointer. Models, specifications, principle of operation, application. *Illinois Testing Labs.*

463. Controllers
16-page educational Bulletin No. 9 gives data, operation diagrams, schematic drawings of capacitrols. *Wheelco*

464. Copper Alloys
28-page specification index compares trade names and specifications of various agencies. Compositions of alloys. *American Brass Co.*

465. Copper Alloys
14-page bulletin lists properties, forms and composition of wrought copper and copper-base alloys. Corrosion resistance, annealing range, and fabricating properties. *Western Brass*

466. Corrosion Resistance
12-page bulletin on copper-base alloys. Their physical properties, characteristics, uses, techniques for welding. *Ampco*

467. Corrosion-Resistant Alloys
36-page booklet on welding, forging, forming, machining, grinding, brazing, heat-treating, and descaling and pickling Hastelloy B, C, D, and F. *Haynes Stellite Co.*

468. Corrosion Testing
Data on corrosion test cabinets. *G. S. Equipment Co.*

469. Creep Tester
Bulletin on new creep rupture tester designed for laboratory testing of small specimens. *Arcweld Mfg.*

470. Creep Testing
New Bulletin RR-13-56 on testing machines for creep and stress-rupture tests. Tables. *Riehle*

471. Cutting Oil
New folder describing nine types of cutting oils for varied applications. *Gulf*

472. Degreasers
Folder on vapor and solvent degreasers describes equipment and advantages. *Randall Mfg.*

473. Degreasing
Booklet on vapor degreasing. Design, installation, operation and maintenance of equipment. *Circo Equipment*

474. Degreasing
Data sheet 814 on trichlorethylene gives specifications, uses, precautions. *Hooker Chemical*

475. Descaling
New 8-page booklet describes and pictures uses of Rotoblast descaling equipment. *Pangborn*

476. Dew Point
New 6-page folder on automatic dew point recorders and controllers. What they do, how they operate. *Surface Combustion Corp.*

477. Die Steel
Data sheet on Ottawa 63 high-carbon, high-vanadium die steel. Physical characteristics and tests. *Allegheny Ludlum Steel*

478. Ductile Iron
Bulletin on magnesium-ferrosilicon for ductile iron. Analysis of magnesium ferroalloys. Role of magnesium in ductile iron. *Electro Metallurgical*

479. Electric Furnaces
Folder on electric furnaces with zone control, temperature indication, automatic control. *L & L Mfg. Co.*

480. Electric Furnaces
8-page Bulletin 570 on heat treating, melting, metallurgical tube, research and sintering furnaces. Custom designs for special requirements. *Pereny*

481. Electric Heat
New Bulletin GER-1333 on electric heat for plating baths. Installation, power and maintenance. *General Electric*

482. Electric Heating
4-page bulletin on electric heating elements for pipe, tube and tank heating. Sizes, temperature control, element life and installation discussed. *Cooley Electric*

483. Electron Microscope
24-page booklet on use of electron microscope in science and industry. *RCA*

484. Electropolisher
Theory and practice of electrolytic polishing of metallurgical samples, description of electropolisher. Metal Digest, Vol. 1, No. 5. *Buehler, Ltd.*

485. Fans
Bulletins HF 100 and HF 100-A on heat fans. Selection and performance tables. *General Blower Co.*

486. Ferroalloys
16-page booklet on Ferrocarbo gives its effect on microstructure and machinability of gray iron castings. Photomicrographs of segregation. *Electro Minerals Div., Carborundum*

487. Ferrochromium Alloys
New leaflet describing 13 ferrochromium alloys and briquettes and four ferrochrome-silicon alloys. Composition, advantages. *Vanadium Corp.*

488. Firebrick
28-page bulletin R-34 on properties and characteristics of 5 kinds of firebrick. Typical applications. Tables of brick quantities for arches of different sizes and shapes. *Babcock & Wilcox, Refractories Div.*

489. Flow Meters
Bulletin 203 on flow meters for gas used in heat treating. *Waukee Eng'g.*

490. Forging
Brochure on Cameron forging process. *Cameron Iron Works*

491. Forgings
12-page booklet on how forged weldless rings and flanges are made. Case histories. *Standard Steel Works Div., B-L-H*

492. Formed Plate
Bulletin on stainless steel ASME and standard flanged and dished heads. 352 available dies listed. *G. O. Carlson*

493. Formed Shapes
26-page catalog No. 1555 contains drawings and dimensions of more than 100 shapes. *Roll Formed Products Co.*

494. Freezer
Data on chest for use down to −140° F. for production and testing. *Revco*

495. Furnace
New bulletin on basic principles of electric furnace design. Cutaway models of 8 furnaces. Cost factors. *Holcroft*

496. Furnace
4-page bulletin KM-570 on Karbo-Matic automatic furnace for hardening, carbonitriding or carburizing. Operation. Heating elements. *Pacific Scientific*

497. Furnace Belts
44-page catalog describes metal belts for quenching, tempering, carburizing and other applications. *Ashworth Bros.*

498. Furnace Brazing
Folder gives correct procedures for furnace brazing. Design for furnace brazing, brazing materials, atmospheres. *American Platinum*

499. Furnace Controls
Bulletin 658 on saturable reactor for regulation and control of electric ovens and furnaces. *Sorgel Electric Co.*

500. Furnace Elements
24-page Bulletin H on electric heating elements. Tabular data on physical and electrical specifications for various sizes. *Globar Div., Carborundum*

501. Furnace Fixtures
16-page catalog on baskets, trays, fixtures and carburizing boxes for heat treating. 66 designs. *Stanwood*

502. Furnaces
6-page folder on gas-fired, oil-fired and electric furnaces. Typical installations. *Electric Furnace Co.*

503. Furnaces
8-page bulletin on pit-type convection furnaces. Uses, construction, atmospheres, specifications. *Hevi-Duty*

504. Furnaces
New catalog on furnaces and ovens for laboratory or production. *K. H. Huppert*

505. Furnaces
Data on recirculating furnaces. Temperature range 300 to 1650° F. *J. A. Kozma*

506. Furnaces
Brochure describing heating, treating, processing and laboratory furnaces. *L & L Mfg. Co.*

507. Furnaces
12-page catalog on electric heat treating furnaces. Data on each of 57 models. Controls, instruments, elements and accessories. *Lucifer Furnaces, Inc.*

508. Furnaces
Bulletin on metallurgical test furnaces for tensile, creep and stress-rupture tests. Control panels. *Marshall Products*

509. Furnaces
Folder describes complete setup for heat treatment of small tools, including draw furnace, quench tank and high temperature furnace. *Waltz Furnace*

510. Gas Analysis
4-page folder on solutions used for analysis of oxygen, carbon dioxide, unsaturated hydrocarbons and other gases. *Burrell*

511. Gas Plants
Data on anhydrous ammonia plants and standby gas plants. *Peacock Corp.*

512. Germanium
Bulletin on physical characteristics and purity standards of germanium and germanium dioxide used in making semiconductor devices. *Chemical & Metallurgical Div., Sylvania*

513. Gold Plating
8-page paper gives bath composition, equipment and operating conditions, and metallurgical characteristics of 24K gold plate on various base metals. *Sel-Rex*

514. Gold Plating
Physical, thermal, chemical, electrical, diffusion and optical properties of electroplated gold. Uses. *Technic*

515. Graphite
New 12-page booklet on "The ABCs of Colloidal Dispersions". Answers to questions most frequently asked about colloids. *Acheson Colloids Co.*

516. Hardness Numbers
Pocket-size table of Brinell hardness numbers. *Steel City Testing*

517. Hardness Tester
New Bulletin F-1689-3 on Impressor portable hardness tester for aluminum, aluminum alloys and soft metals. *Barber-Colman Co.*

518. Hardness Tester
20-page book on hardness testing by Rockwell method. *Clark Instrument*

519. Hardness Tester
Bulletin A-16 on microreflex hardness testers. Loads to 3000 gr. Zeiss optical system. *Gries Industries, Inc.*

520. Hardness Tester
Bulletin on Brinell tester with test head for deep and offset testing. *King Tester*

521. Hardness Tester
Data on portable hardness tester with Rockwell and Brinell scales. *Mechanical Devices*

522. Hardness Tester
Catalog 72-1 on Leitz miniload tester for Vickers and Knoop hardness tests. *Opto-Metric Tools, Inc.*

523. Hardness Tester
Bulletin S-33 on vertical-scale and dial-indicating scleroscopes. How they are calibrated. *Shore Instrument*

524. Hardness Tester
Data on hardness testing scleroscope with equivalent Brinell and Rockwell C numbers. *Shore Instrument*

525. Hardness Testers
Folder on portable hardness testers for testing of various sizes, shapes and types of metal. *Newage Industries*

526. Hardness Testers
4-page bulletin on hardness tester for regular and superficial Rockwell tests. Special features and accessories. *Torsion Balance*

527. Hardness Testers
Catalog of testers for normal hardness, superficial testing, accessory and special testing and micro and macro hardness testing. *Wilson Mechanical Instrument*

528. Heat Treat Pots
Catalog on pressed steel pots for lead, salt, cyanide, oil tempering and metal melting. *Eclipse Industrial Combustion*

529. Heat Treating
8-page bulletin on heat treating. Data sheets on processes and processing equipment. Also covers annealing, brazing and hardening. *Ferrotherm*

530. Heat Treating
Monthly bulletin on used heat treating and plating equipment available for immediate delivery. *Metal Treating Equipment Exchange*

531. Heat Treating
Bulletin 14-T on ovens for heat treatment of aluminum and other low-temperature processing. *Young Bros.*

532. Heat Treating Ammonia
24-page "Guide for Use of Anhydrous Ammonia" describes heat treating and other metallurgical uses. *Nitrogen Div.*

533. Heat Treating Fixtures
Bulletin on formed and welded alloy heat treating furnace fabrications. *Alloy Engineering Co.*

534. Heat Treating Fixtures
4-page folder on retorts, baskets, trays, carburizing boxes, fans for heat treating. *Aluminum & Architectural Metals Co.*

535. Heat Treating Fixtures
24-page catalog on heat and corrosion-resistant equipment for heat treating and chemical processing. 30 classifications of equipment. *Pressed Steel*

536. Heat Treating Fixtures
32-page Catalog G-10A lists process equipment, heavy welded fabrications, muffles, trays, fixtures for furnaces, heat treating equipment, pickling equipment. *Rolock*

537. Heat Treating Fixtures
16-page Catalog M-7 on heat treating baskets and corrosion resistant alloy fabrications. *Wiretex Mfg. Co.*

538. Heat Treating Furnaces
New Bulletin No. HT-53 on heat treating furnaces. Construction, design, fuel used. *Carl-Mayer*

539. Heat Treating Furnaces
Folder on industrial furnaces. Continuous designs. Insulation. *Pacific Industrial*

540. Heat Treating Pots
Bulletin 110 gives data on sizes and shapes of cast nickel-chromium solution pots. *Fahralloy*

541. Heat Treatment
Bulletin 200 on car hearth, rotary hearth, pit, roller hearth, belt, chain, pusher, and "hi-head" furnaces. *R-S Furnace*

542. High-Alloy Castings
16-page bulletin. No. 3354-G, gives engineering data concerning castings used for resisting high temperatures, corrosion and abrasion. *Duraloy Co.*

543. High-Strength Steel
24-page bulletin on steel bars made by elevated temperature drawing. Strength without heat treatment, machining, wearability. *LaSalle Steel*

544. High-Strength Steel
Data sheet and 16-page folder on VascoJet 1000, 5% chromium air hardening steel. Mechanical properties, fatigue strength, heat treatment and surface properties. *Vanadium-Alloys Steel Co.*

545. High-Strength Steels
Folder on manganese-copper steels. Properties, fabricating practice. *Republic Steel*

546. Induction Heating
36-page bulletin on high-frequency induction heating unit for brazing, hardening, soldering, annealing, melting and bombarding. *Lepel*

547. Induction Heating
12-page booklet on the A-B-C's of induction heating for extrusion, forging, brazing, heat treating and metal joining. *Magnethermic*

548. Induction Heating
4-page folder on use of induction heat treating, hardening, brazing at Caterpillar Tractor. *Ohio Crankshaft*

549. Induction Melting
Folder R-42 on line frequency induction melting furnaces in modern zinc and aluminum die casting plant. *Ajax Engineering Corp.*

550. Inspection
Bulletin on Spotcheck dye-penetrant inspection. Advantages, prices. *Magnaflux Corp.*

551. Inspection
Data on multi-frequency inspection of nonferrous and nonmagnetic metals. *Magnetic Analysis*

552. Inspection
16-page catalog on illuminated Borescopes for industrial inspection of deep recessed areas. *National Electric Instrument Div.*

553. Insulators
Bulletin P1-55 on insulators and insulating tubing. *McDanel Refractory Porcelain*

554. Laboratory Equipment
New bulletin on cutting test specimens describes methods for different types of metals. Price list. *Sieburg Industries*

555. Laboratory Furnace
Data on nonmetallic resistor furnaces for research, testing or small-scale production. *Harrop Electric Furnace*

556. Laboratory Furnace
Information on 4600° F. laboratory furnace. Bottom-dropping hearth; for use with oxyacetylene or natural gas burners. *Zirconium Corp.*

557. Laboratory Supplies
Instruments and apparatus for control,

research, development laboratories. *Harshaw Scientific*

558. Leaded Steels
16-page booklet on basic characteristics, mechanical properties and workability of leaded steels. Case histories. *Copperweld Steel Co.*

559. Leak Detector
New 8-page Bulletin 4-62 on consolidated auxiliary test stations for leak detection. Production rates, applications, operating features. *Rochester Div., CEC*

560. Lubricants
8-page booklet on colloidal greases, forging compounds, hydraulic concentrate and others. *Grafo Colloids*

561. Lubricants
Bulletin 581 on colloidal graphite dispersions for industry. 17 uses listed. Tables on concentrated and ready-to-use solutions. *Graphite Products Corp.*

562. Manganese
Technical Data Bulletin 201 on electromanganese and nitrelmang. Product characteristics. Composition. *Foote Mineral*

563. Melting
Bulletin GEA-6113A, on how to select cast-in immersion heaters, controls and melting pots for soft-metal melting applications. *General Electric Co.*

564. Melting Furnaces
32-page catalog on Heroult electric furnaces. Design, types, sizes, capacities, ratings. *American Bridge*

565. Metal Marking
New bulletin on all purpose electric pen which will arc etch any metal. *Newage Industries*

566. Microhardness Tester
Bulletin describes the Kentron microhardness tester. *Torsion Balance*

567. Microscopes
New 8-page Bulletin SB2200-1157 on metallurgical microscopes. Accessories. *American Optical*

568. Microscopes
Catalog on metallograph and several models of microscopes. *United Scientific*

569. Nickel-Base Alloy
New Technical Data series No. 86 on René 41, vacuum-melted nickel-base alloy. Properties. Temperature range, 1200 to 1800° F. *Cannon-Muskegon*

570. Nickel Plating
New 24-page booklet answers questions about physical and chemical properties of the coating and its machining, welding and forming possibilities. Plating techniques and design factors. *International Nickel Co.*

571. Nickel Wire Cloth
15-page booklet gives applications, standard weaves, properties of nickel-alloy wire cloth. *International Nickel Co.*

572. Nondestructive Testing
8-page bulletin on equipment for nondestructive testing of bars, rods, tubing. *Magnetic Analysis*

573. Nonferrous Wire
Folder gives wire gage and footage chart and data on beryllium copper, phosphor bronze, nickel, silver, brass and aluminum wire. *Little Falls Alloys*

574. Nuclear Forgings
6-page brochure on carbon, alloy and stainless steel forgings for nuclear reactor applications. *U. S. Steel Corp.*

575. Oil Quenching
8-page brochure tells in detail how carbon steel often can replace alloy steel when additive is used in the quenching oil. *Aldridge Industrial Oils*

(Continued on page 48-A)

(Continued from page 47)

576. Optical Parts
New 16-page Catalog L-117 on full line of optical parts. 28 tables. *Bausch & Lomb*

577. Ovens
Bulletin 4-257 on gas, oil and electric ovens. Load carrying door, electric drawer and walk-in type ovens. *Grieve-Hendry*

578. Phosphating
Free phosphating analysis kit to determine if products are adaptable to phosphating. *Turco Products*

579. Phosphor Bronze
Facilities for rolling, cleaning, welding, trimming and treating phosphor bronze. *Rolling Mill Div., Miller Co.*

580. Plating
8-page brochure on test equipment for plating baths. Controls, anodes, cathodes, agitators, rectifiers. *R. O. Hull*

581. Plating Thickness Tester
Data sheets give ranges, principle of operation of nondestructive thickness tester. *Unit Process Assemblies*

582. Potentiometer
New 64-page bulletin P1245A on electronic potentiometer and bridge instruments for recording, controlling. *Bristol*

583. Pouring Practice
New 8-page brochure gives six hints on improving metal pouring practice. *Vesuvius Crucible Co.*

584. Powder Metallurgy
12-page bulletin B-101 on furnaces for sintering powder metal products and reduction of metallic oxides. *Drever*

585. Powder Metallurgy
4-page folder presents extensive powder metallurgy bibliography for 1954 and 1955. *Harper Electric*

586. Powder Metallurgy
Technical literature on high-density sintered metal parts. *Supermet Div., Globe Industries*

587. Precious Metals
4-page bulletin describes the forms of wastes in which valuable precious metals can be hidden. Types of scrap materials that have salvageable values. *Handy & Harman*

588. Precision Casting
8-page bulletin on investment castings of various ferrous and nonferrous alloys. *Engineered Precision Casting*

589. Presses
Data on mechanical and hydraulic powdered metal presses 8 to 500-ton capacities. *Haller, Inc.*

590. Presses
12-page brochure on horizontal, multi-station, automatic redraw presses. Details on 12 machines; advantages of multiple-station deep drawing; attachments. *Waterbury Farrel Foundry & Machine*

591. Protecting Tubes
Bulletin 1000-56 on ceramic protecting tubes lists sizes and materials. *Claud S. Gordon*

592. Pyrometers
Catalog 168 on surface pyrometer for surface and subsurface temperature readings. *Pyrometer Instrument*

593. Quenching
Catalog FR-853 on two small self-contained quenching units. *Bell & Gossett*

594. Quenching
16-page booklet on modified and full marquenching procedures. Hardness and dimensional control data, cooling curves, case histories. *Sinclair Refining Co.*

595. Radioactive Chemicals
24-page booklet describes radioactive chemicals and their uses. Lists those available. *Baker & Adamson.*

596. Radiography
Reprint from Canadian Metalworking describes gamma radiography machines which can be used to radiograph sections up to 10 in. *Budd Co.*

597. Radiography
16-page booklet on materials and accessories for industrial radiography. Guide to selection of film. Recommended development techniques. *Eastman Kodak, X-Ray Div.*

598. Recorders
New Bulletin COM on temperature recorders, controllers, indicators and control systems. Accessories. *West Instrument*

599. Refractories
12-page booklet on 6 types of firebrick. Tables of thermal data on vertical walls. Conductivities of insulating firebrick. *Harbison-Walker Refractories*

600. Refractories
Revised 8-page Brochure IN-115A on products for casting special refractory shapes and for gunning and troweling applications, for service to 3000° F. *Johns-Manville*

601. Refractories
16-page Catalog 1795, "Crucibles for Metal Melting". Physical and chemical characteristics, uses and availability of various refractory products. *Norton*

602. Refractories
40-page book lists super-refractories for heat treating furnaces and gives data on use in different kinds of furnaces. *Refractories Div., Carborundum*

603. Refractory Metals
Booklet on tungsten, molybdenum, tantalum, their properties and uses. *Fansteel Metallurgical*

604. Resistance Alloys
New 20-page booklet M-57A on 80-20 nickel-chromium alloy. Heating element design data. Metallurgical factors which affect high-temperature operations. *Hoskins Mfg.*

605. Resistance Welding
28-page bulletin gives principles of resistance welding, resistance welding formulas, data on how to calculate welding pressures, time in cycles, current. *Federal Machine & Welder Co.*

606. Rust Prevention
Nine bulletins in one folder on rust prevention. Theory of corrosion. *Production Specialties*

607. Rust Preventive
Bulletin on wetting agent and emulsifier for use as a rust preventive and corrosion inhibitor. *Swift & Co.*

608. Saws
Catalog C-55 describes 35 models of metal-cutting saws. *Armstrong-Blum*

609. Slitter
16-page booklet on rotary gang slitters. Sheet and coil slitting methods summarized. *Stanat Mfg.*

610. Spectrographic Electrodes
New 24-page catalog S-58 on spectographic graphite products describes manufacturing steps, shapes and designing of high-purity pre-formed electrodes. *United Carbon Products*

611. Spectrometer
Bulletin on Atomcounter direct reading spectrometer describes instrument and pulse computer system. *Jarrell-Ash*

612. Sponge Iron
New 8-page brochure on HyL process for converting iron ore into sponge iron. Tables show ore analysis, sponge iron analysis, costs. *M. W. Kellogg Co.*

613. Spray Coating
New 4-page folder on equipment for airless spray coating includes discussion of process, temperatures, pressures, advantages. *Nordson Corp.*

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24-page booklet on stainless bar and wire. Forms available, grades. Advantages, properties, fabrication, electropolishing, ebonizing. *Armco Steel*

615. Stainless Steel
New data sheets covering 17 types of stainless steels. Chemical composition, applications, processing, physical and mechanical properties, machining, forming, welding. *Jones & Laughlin*

616. Stainless Steel
32-page catalog gives chemical composition, strength factors, physical properties and applications of 200, 300, 400 series stainless. *Sharon Steel*

617. Stainless Tubing
12-page brochure on stainless steel heat exchanger and condenser tubes. Manufacture, chemical composition and analysis. *Republic Steel*

618. Steelmaking
24-page booklet on melting, forging, heat treating, machining and other facilities. Type of products produced. *Midvale-Heppenstall Co.*

619. Steelmaking Additive
Data on additive which cleans melts without changing analysis. *WaiMet Alloys*

620. Strip Mill
Data on cold reduction mill. *Loma Machine Mfg. Co.*

621. Sub-Zero Treatment
New 12-page Bulletin 103 on industrial chilling equipment for shrinking, testing and treating of metals. *Cincinnati Sub-Zero Products*

622. Sulphur Determination
New 16-page catalog describes sulphur and carbon determinators. Accessory equipment and supplies. *Harry W. Dietert*

623. Tantalum
New 4-page folder on applications of high-purity tantalum. Forms in which it is available, chemical analysis. *NRC Equipment Corp.*

624. Temperature Control
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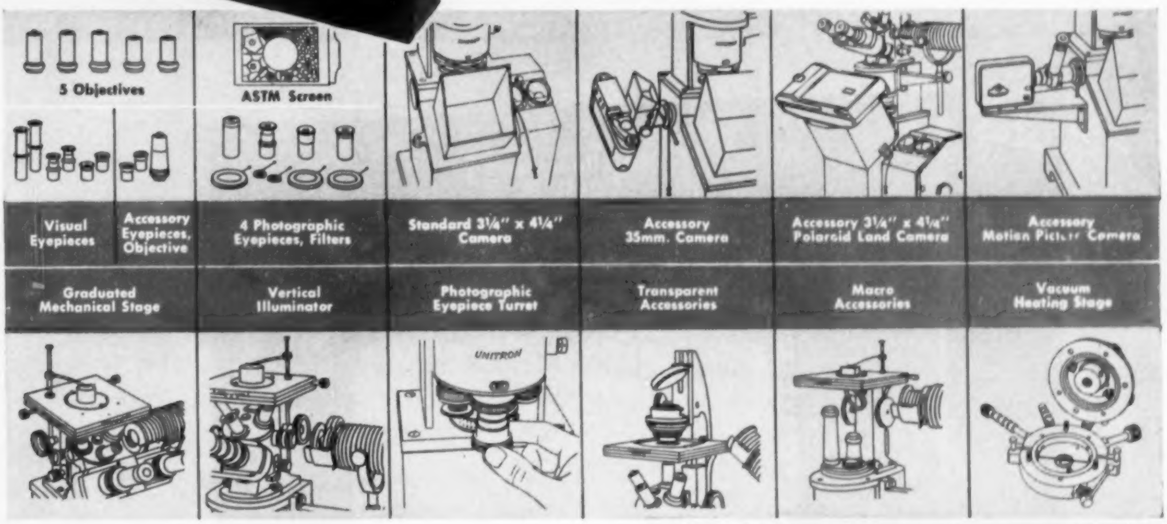

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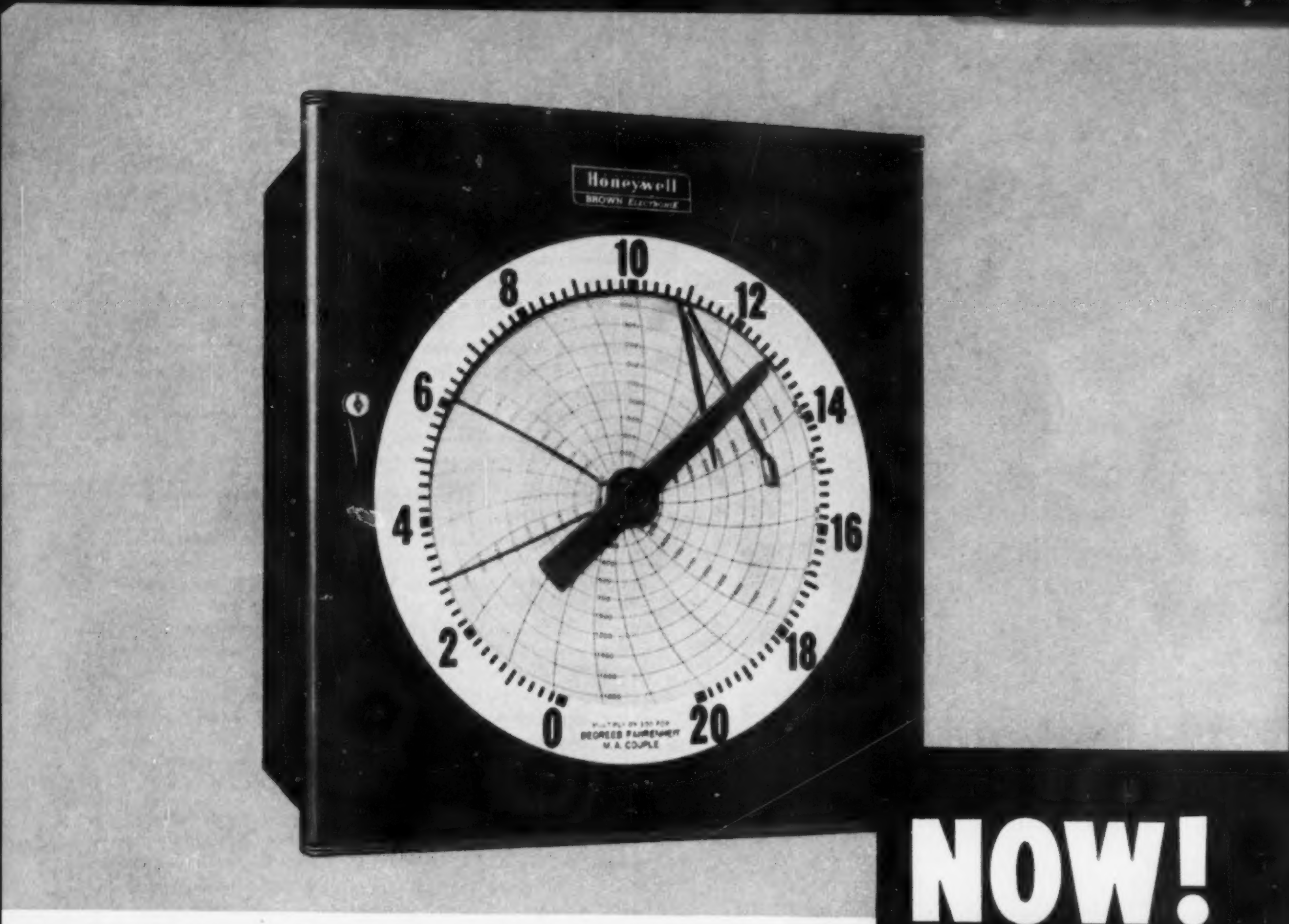

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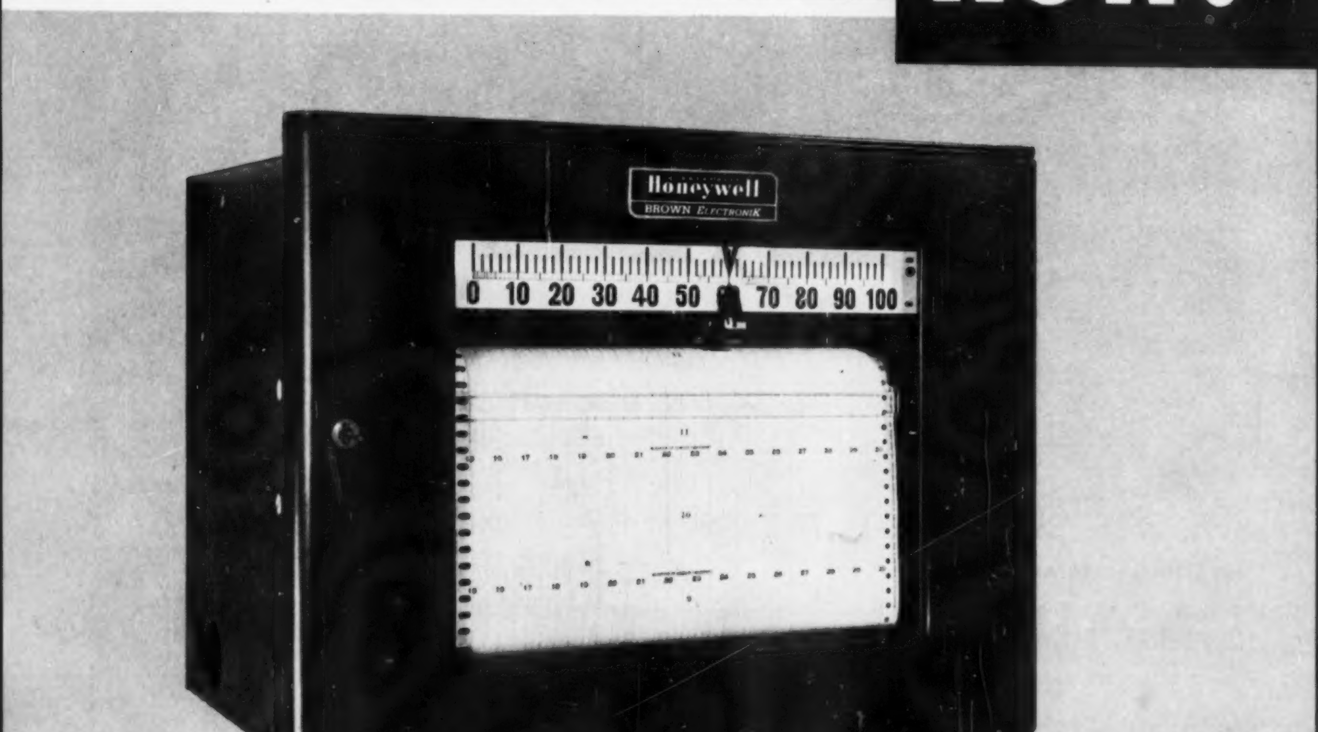

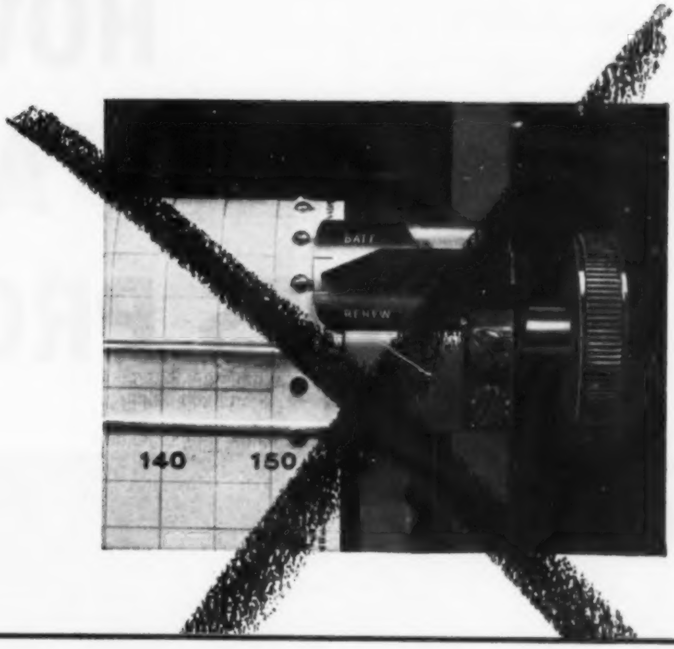

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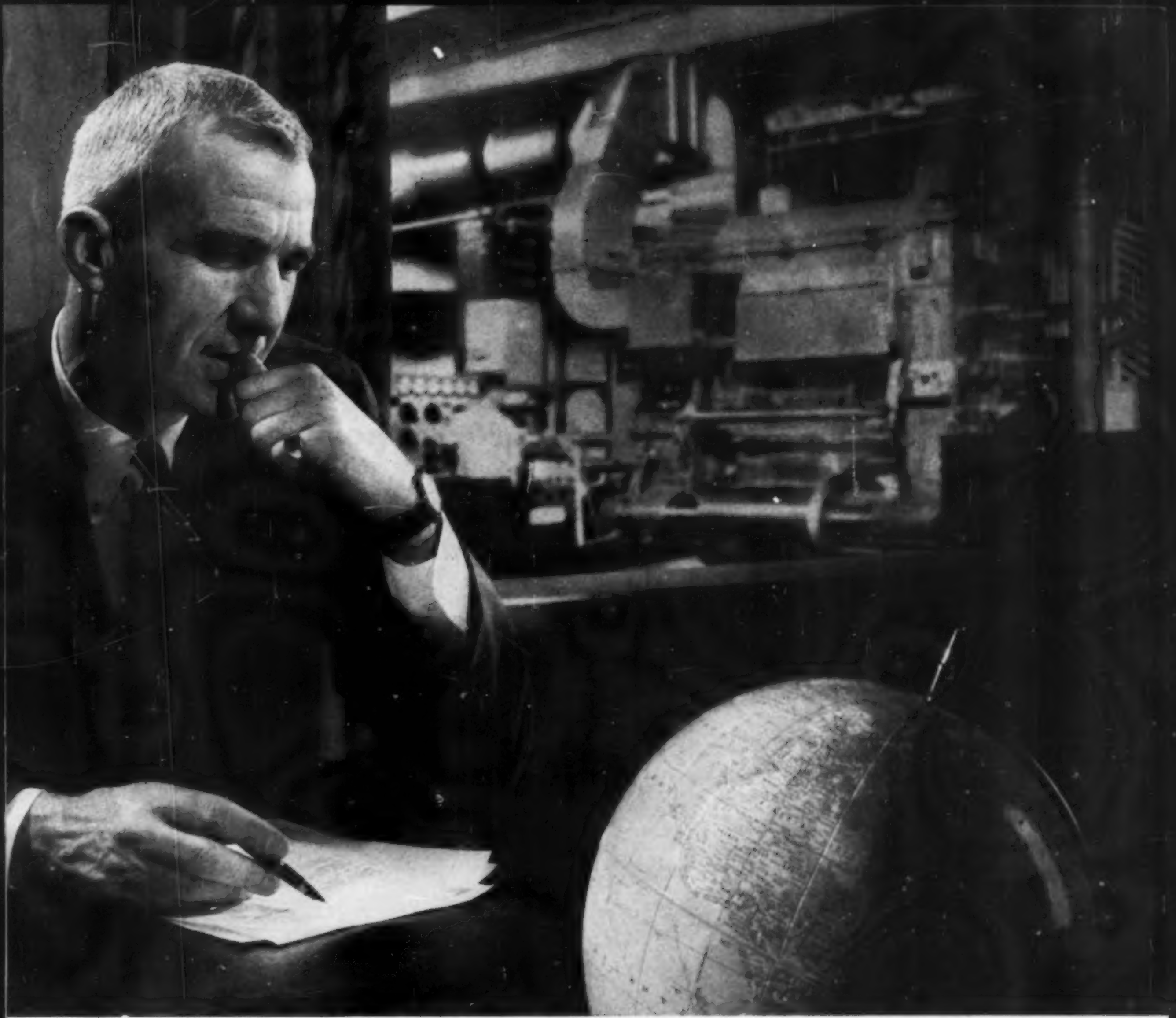

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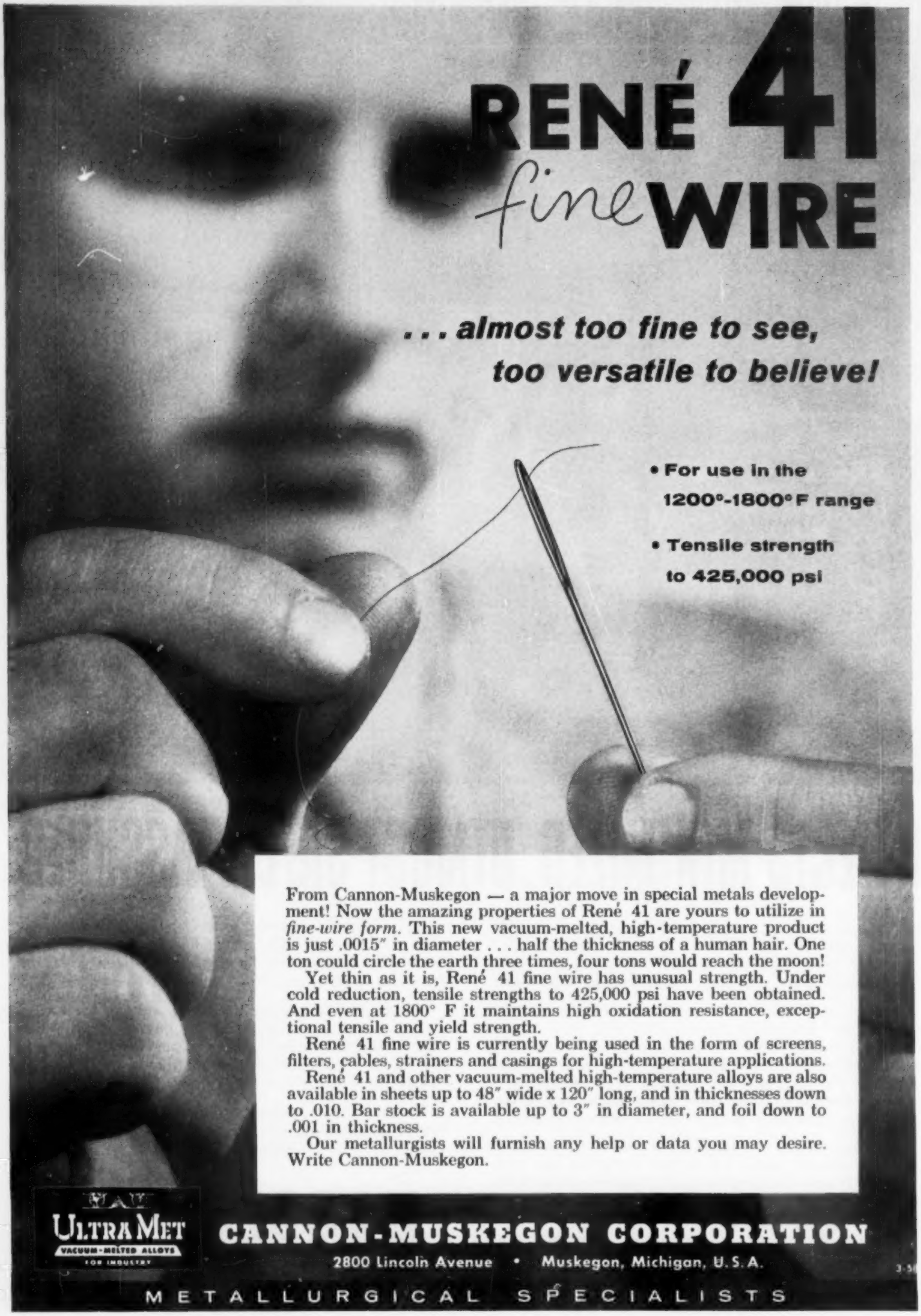
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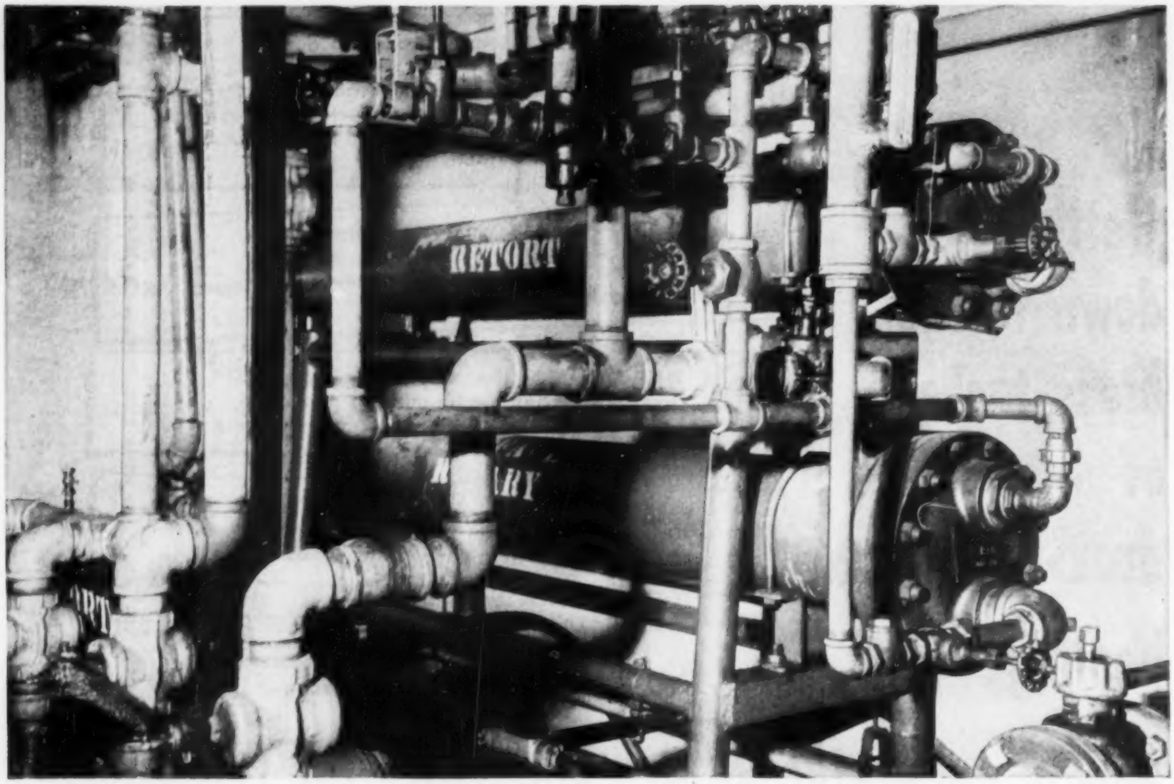

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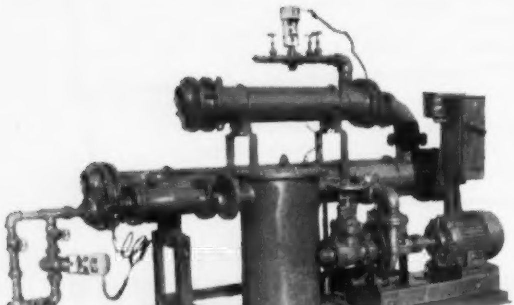

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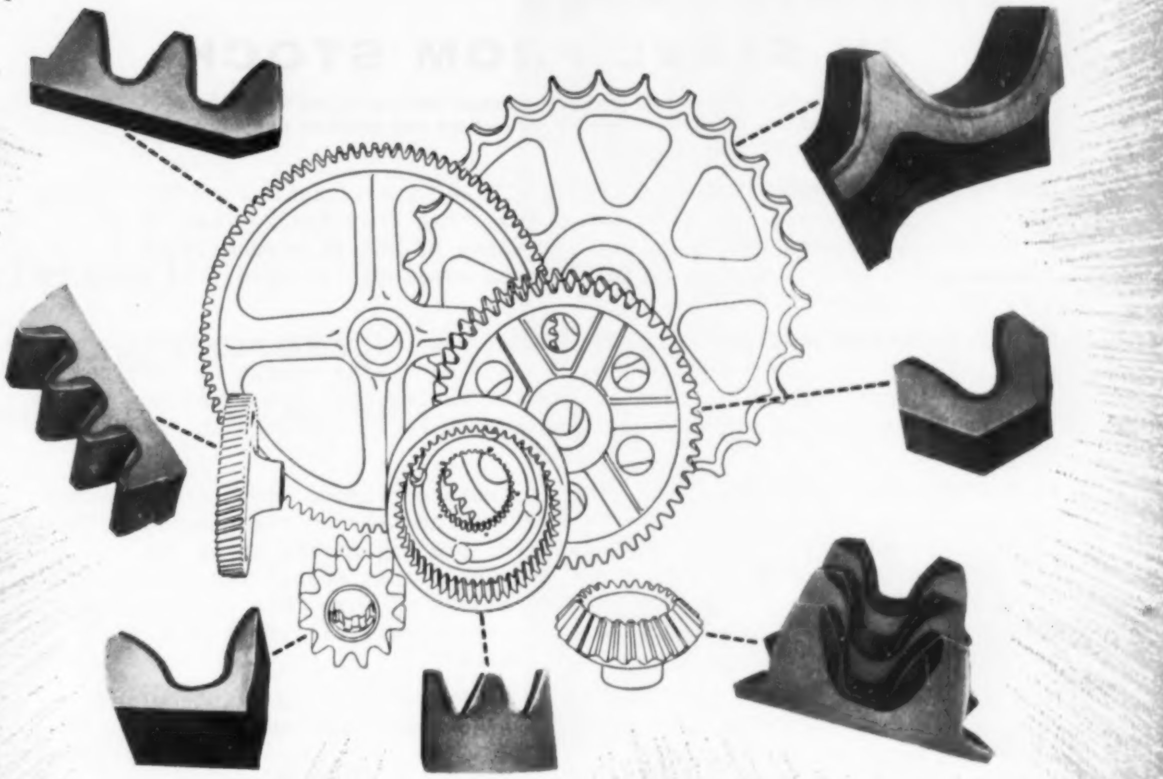

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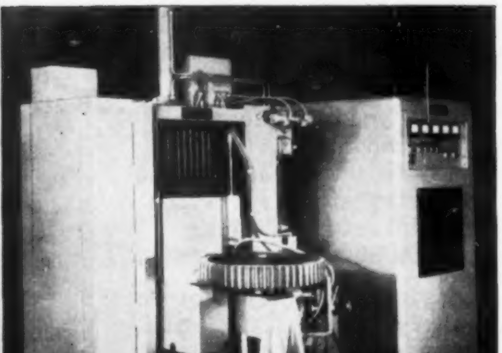

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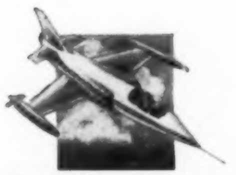
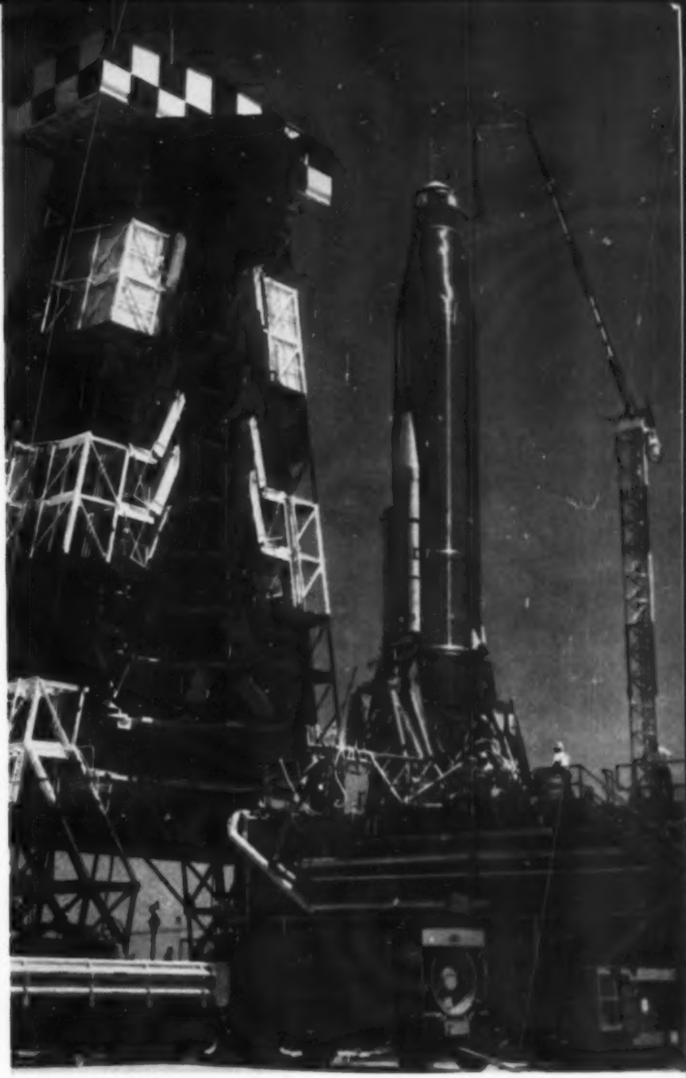
Metal ..Progress

Volume 75, No. 3 **March 1959**



Producing for the Supersonic Age



More than 40,000 parts, all with stiff engineering requirements, make up the Atlas ICBM shown above. Now in pilot production in San Diego by Convair (Astronautics) Div. of General Dynamics Corp., the big missile is scheduled for full operation by the end of this year. Although billions are going into missiles and advanced aircraft (over $11 billion in our defense budget for '59), money isn't the whole story of their impact on industry. As products, they have unprecedented "engineering" content because no manufacturing has ever demanded so much technical competency. The next generation of the birds – requiring fabricators to work with still newer materials to get lighter, stronger structures – will call for even more engineering content.

As the features in this issue will show you, aircraft and missile work is a diverse and challenging field. Success almost invariably requires a high degree of capability in some area of metal manufacturing. There are plenty of problems, but the rewards for pioneering can be rich.

The potential of a new material or improved method is usually much broader than anticipated originally. Ten years hence it's almost certain that every plant in the United States turning out metal goods will be using at least one production method or material that doesn't exist today. Many of these will be developed to solve aircraft and missile problems, but applications will expand in many directions.

Fuel Containers for Rockets

*By DONALD E. NULK**

Weight restrictions, high pressures and wide operating temperature ranges – all must be considered in producing missile fuel vessels. Material choice is limited, and optimum joining methods are still to be developed. Careful testing is needed to determine the quality of both factors. (T2p)

ONE would think that experience gained from the boiler industry would serve missile builders well. Actually, weight problems in missiles force the consideration of much stronger materials along with lower safety factors. Both requirements intensify our problems. With safety factors as high as 10 to 1 being used in fabricating boilers, certain physical and structural discontinuities can be tolerated. Operating stresses are well below the yield strength even in areas of stress concentration.

However, pressure vessels for the missile industry use safety factors around 1.05 to 1.1 (based on the yield strength or ultimate strength as dictated by the application). Any distortion, structural inhomogeneity or physical discontinuities can cause local yielding where stresses are concentrated. This forces a careful analysis of all processing techniques, and restricts the choice of materials.

Let us take a look at two typical pressure vessels. Figure 2 shows a spherical container typical of those used to hold gases at –320° F. in a liquid fuel missile, and Fig. 3 illustrates a typical motor case employing the maximum amount of welding. In the latter, the forward opening permits insertion of the core around which the solid fuel is cast, and the aft flange is attached to the nozzle assembly. This unit must withstand high shock bending loads in transport, and high shock hoop stress in firing. Furthermore, it is exposed to elevated temperatures the last few milliseconds of firing.

Although both types of pressure vessels present analogous fabrication problems, the greater variety of process variations exist with the motor case. Let us consider some of these.

Fabricating the Case

This is no easy matter. The cylindrical sections are made from sheet which is rolled, welded with a longitudinal seam, and sized. End closures are forged, spun, or drawn, and circumferential welds join them to the cylindrical sections.

The units must be heat treated after complete fabrication. Accurate size control is necessary, to hold distortion to a minimum. As an example, a typical 40-in. case may require the diameter to be held to ±0.020 in., while the "out of round" is controlled within 0.150 in.

The major disadvantage of this fabrication

*Senior Project Engineer in Design Metallurgy, Thompson Ramo Wooldridge, Inc., Cleveland.

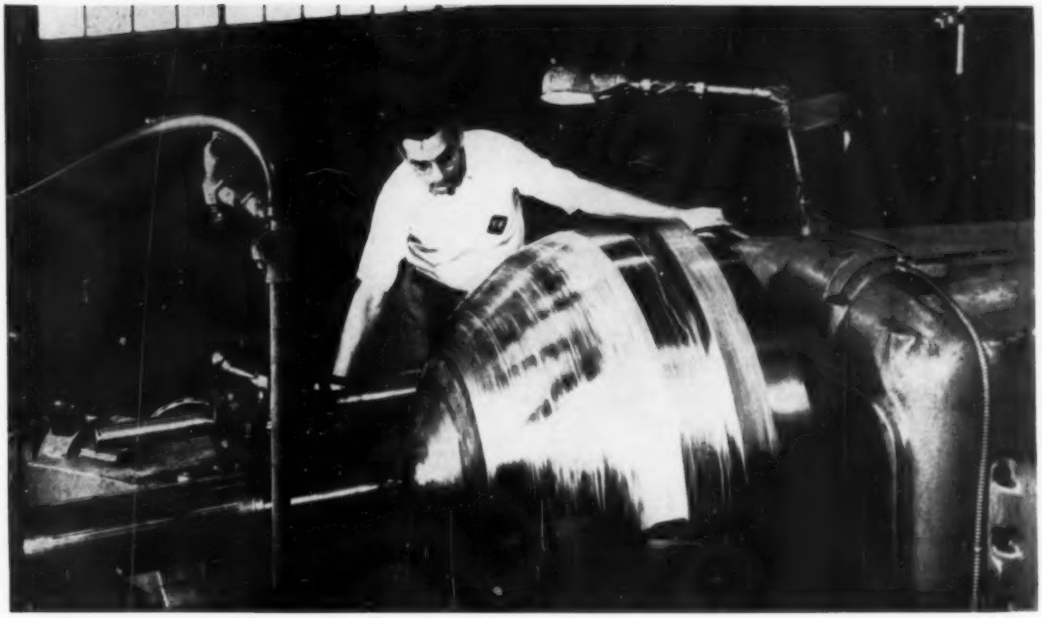


Fig. 1 – Forming a Hemisphere for a Liquid Fuel Case

method lies in the longitudinal welds. Since the hoop stress is about double the longitudinal stress, it is necessary to have much stronger joints in the longitudinal direction. Designers tend to shy away from welds because of structural or physical discontinuities which lead to high stress concentrations.

However, this method has some advantages. It is low in cost, requires a relatively small capital investment for tools, and near optimum weight-to-strength ratios are possible – if the welding problems are solved. To illustrate, a designer may have a case which requires a wall thickness of 0.100 in. to meet his strength needs. If we use mill sheet, we'll add a ±0.008-in. tolerance for gage variation and an additional 0.004-in. tolerance for decarburization or surface imperfections. This means that we could have

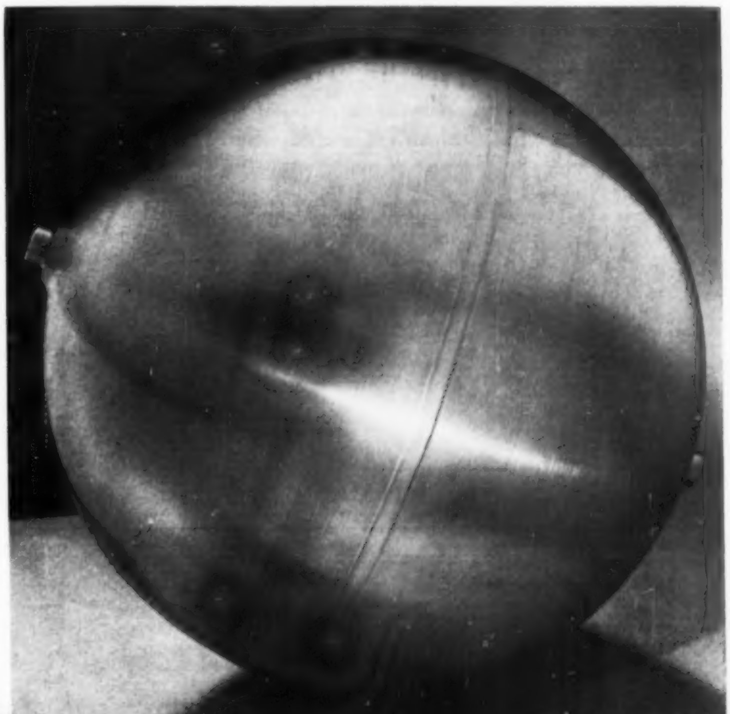


Fig. 2 – Spherical Fuel Container for Gases at Low Temperatures. The bosses on either end act as both support and pumping ports

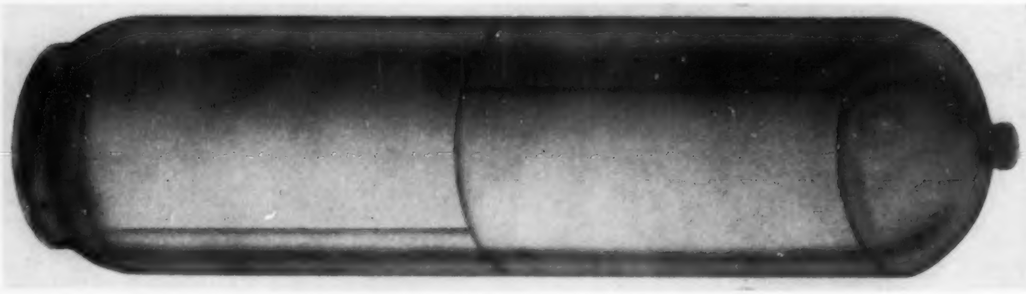


Fig. 3 – Solid Fuel Container With Maximum Amount of Welding. This type is easiest to fabricate, but stress problems are introduced by the number of welds

material as thick as 0.124 in. to insure a usable 0.100 in. of material for the designer. If we pack roll the sheets, we can cut the gage tolerance by a factor of three or four. These sheets can then be surface ground, to give a final product with no decarburization or surface pits and a gage tolerance of about 0.002 in. This tolerance variation is difficult to hold with some of the other fabrication methods.

Case Without Joints

The other extreme in fabrication processes is a case without joints. One method is similar to that used in making gas bottles for oxygen or nitrogen. A plate is cupped and extended into a large closed-end tube by a draw-bench technique, and the end closed by forging. Subsequent machining gives the final product.

Shear spinning provides a modification of this technique. However, both of these techniques require a large capital investment in machines and tools.

Since no one has yet proved that reasonable tolerances can be held with the draw-bench technique, it may be necessary to machine all over during one stage of fabrication. Size control is, theoretically, better with shear spinning although all the problems are not solved. End closures in both methods are a major problem; most designs involve a heavier wall thickness at the aft end than in the cylindrical section of the missile.

Compromise Method

Figure 4 illustrates a compromise between these two systems. Longitudinal welds are eliminated. A single circumferential weld joins the two halves which can be made by drawing or shear spinning. The major problem here is one of equipment or high capital investment. Further, the method becomes less feasible with increase in missile size. Surface imperfections become a major problem and side-wall tolerances are quite touchy. To reach the ± 0.002 in. possible with the first method would require considerable refinement over present-day fabrication knowledge.

Another modification involves the use of one or more cylindrical sections joined to two end closures, as in the first method. However, these cylindrical sections can be made by seamless tubing techniques, shear spinning of drawn parts, or by methods somewhat analogous to the rolled ring process. Again, tolerance and equipment problems exist if we are to approach the idealis-

Fig. 4 – Solid Fuel Container With One Weld in Center. Fabrication is quite difficult though welds are reduced in number

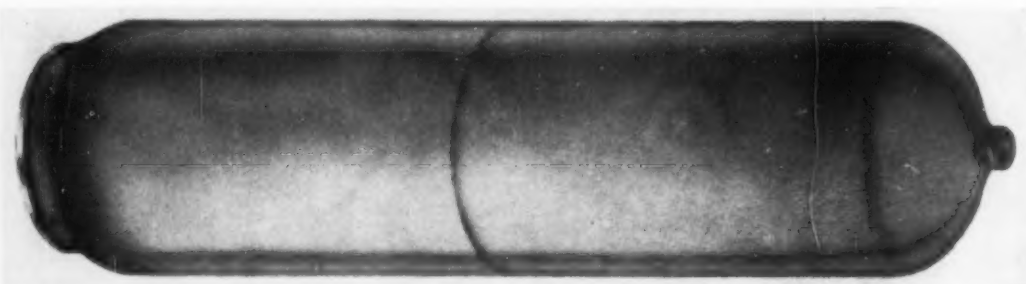
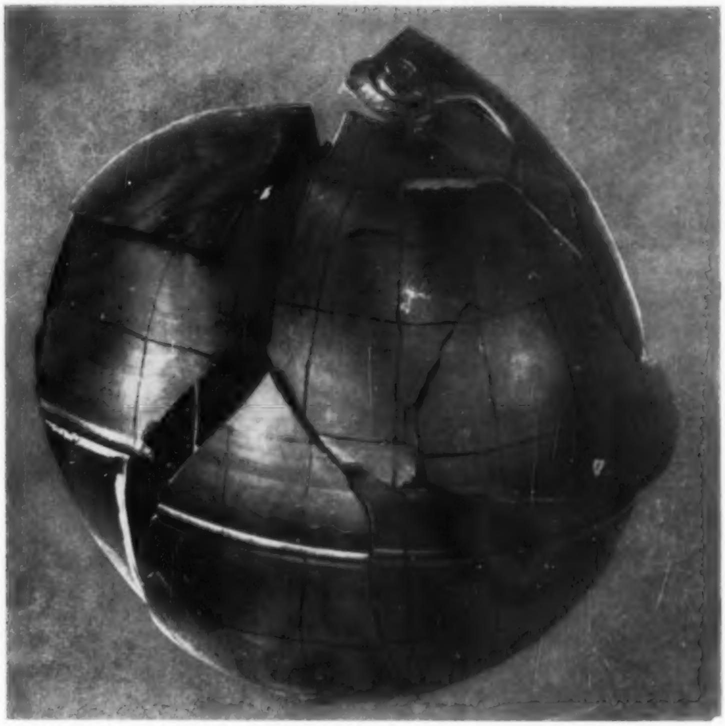


Fig. 5 – Welded Spherical Fuel Container Tested to Failure at −320° F. Since failure was in parent metal, weld design was successful



tic aim of ± 0.002 in. All of these methods are under investigation, and only time will tell the true advantages of each.

Selection of Materials

Materials used in pressure spheres for holding low-temperature gases have stringent requirements. These spheres are subject to shock loading at room temperature during transport. They are also exposed to shock loading at very low temperatures during take-off. Since failure cannot be tolerated in a missile, high reliability at high strength is required. Ductility is essential to permit local yielding.

Considering all these factors, we must eliminate the iron-base martensitic alloys. The austenitic alloys have a lower strength-to-weight ratio than titanium alloys. However, the all-beta titanium alloy, B 120-VCA, is not suitable because it lacks dimensional stability at low temperatures. Some other new alloys, such as MS-185, have welding and ductility problems that have not yet been resolved. We can look forward to improvements of all the alloy groups, but titanium alloys appear the most promising. Of these, Ti-6Al-4V seems to be the best for this particular application. However, the specific material best suited for an application can vary

Fig. 6 – Typical Fracture Surfaces From Broken Container Shown in Fig. 5. Chevrons pointing in different directions indicate that failures nucleated at several points, and propagated to form fractures

greatly with the particular design requirements and operating conditions.

Fabricating Motor Cases

Many factors affect production of motor cases. Cost, weight, and facilities all vary depending upon the missile size and the production quantities involved. Therefore, this paper is limited to a discussion of missiles about 24 to 72 in. in diameter. Smaller missiles, such as the air-to-air type, are usually high-production items with relatively low temperature demands and less emphasis on weight. Larger missiles (for space exploration) involve problems that will not be solved for a long time.

Modified 4340, modified 5% chromium steel, modified 12% chromium steel, austenitic alloys, and titanium alloys have all been considered. As far as strength-to-weight ratios* are concerned, modified 4340, modified 5% chromium steel and the titanium alloys appear to be the best. None of these has yet established a long history of capabilities in the 1,000,000 strength-to-weight ratio range, although specific cases have been made near this value from all three materials. We believe the most promising contender is the titanium-base alloy, for the following reasons:

1. The notch sensitivity is as low, if not lower, than the other two for the same strength-to-weight ratio.

2. Since present strength level in the ferrous alloys represents many years of development, percentage improvement in the future will probably be quite low. On the other hand, titanium-base alloys are comparatively new; there should be much room for improvement.

3. Although motor cases were originally designed for a 1000° F. maximum, many actual cases have been cold enough to touch after test firing. Since it seems reasonable to assume that 400° F. is a more accurate limit for some cases now in development, we should consider alloys that will meet requirements in that range. Most titanium alloys are quite usable at 400° F. within the time limitations imposed.

Design Criteria

Joint designs become very important. We need to increase their quality to meet the designer's demands. It looks as if we can make some advances in welding techniques to improve joint quality, but in the meantime we must continue to make missiles. Consequently, modifications in ideal joint design are necessary.

Two typical modifications are now in use. We can modify the chemical analysis across the weld joint. An example is the use of A.M.S. 6434 as a filler metal in welding S.A.E. 4340. This lowers the carbon content which improves weldability, and raises the vanadium content which corrects the response to heat treatment. We can also use a vacuum-melted Type 6130. Here, lower phosphorus, sulphur and carbon increase weld ductility. There is also a modification of the chromium-nickel-molybdenum ratios.

The second method is to reinforce the weld joint itself. Lower stress across the weld allows the use of a ductile but weaker weld metal. Both of these modifications, incidentally, are in use.

Figure 5 shows a pressure vessel welded by a modified technique which has been tested to failure at −320° F. As can be seen, there was no consistent pattern of failure through the weld. Several cracks started at various locations and propagated until they joined to form a fracture. An area of the failure shown in Fig. 6

*The strength-to-weight ratio is obtained by dividing the ultimate strength by the density in pounds per cubic inch. The yield strength can also be used.

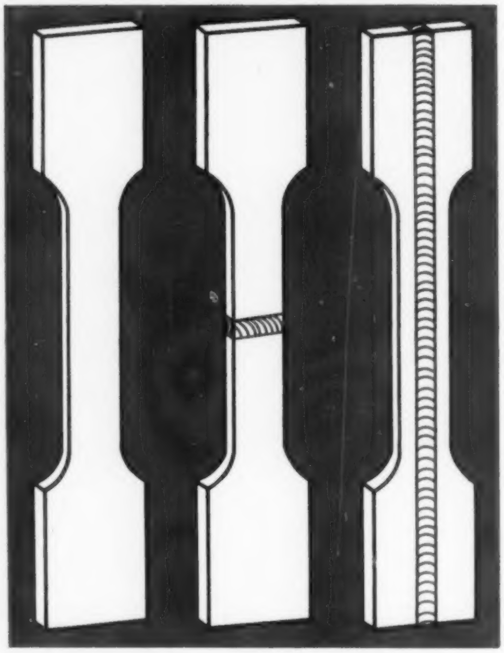
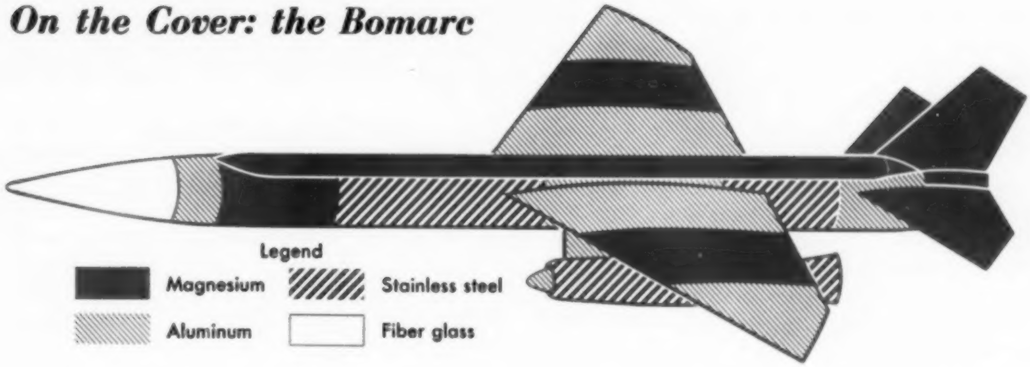


Fig. 7 – These Three Tensile Tests Can Determine Quality of Weld Design and Parent Metal. Their combined results can decide which material and welds are suitable for extensive final tests

On the Cover: the Bomarc



The Bomarc which adorns this month's cover is a long-range, high-altitude, supersonic missile designed to intercept and destroy enemy aircraft and missiles before they come near the United States. The diagram above, prepared by Boeing Airplane Co., builder of the Bomarc, portrays the materials used in the structure of the missile. Other Bomarc specifications: wing span, 18 ft.; over-all length, 47⅓ ft.; height, 10¼ ft.; width of the tail's horizontal planes, 10½ ft.; weight, 15,000 lb. gross.

The supersonic missile is launched by a liquid fueled rocket (Aerojet-General) and powered in flight by two ramjet engines (Marquardt Aircraft). An advanced Bomarc now under development will employ a solid propellant rocket engine and new ramjet engines which have been tested at Mach 4 speed at altitude of 100,000 ft. These changes will increase the missile's range from the present 200 miles to about 400 miles with a substantial increase in speed and altitude capabilities. The Bomarc is guided to the intercept area from the ground. From that point, the missile takes over its own guidance, seeks and destroys any enemy target within its range.

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contains different fracture facets indicating the number of cracks that propagated to form this failure. This vessel failed in the parent metal at internal pressures well above designers' requirements, justifying the joint design.

In considering the 100% joint with no physical discontinuities, we assume that the filler metal must be identical in its deposited form to the parent metal. Advances in inert-gas and submerged-arc welding in recent years have done much toward accomplishing ideal chemical analyses across the weld joint. Two major areas of improvement toward this 100% aim include control of grain size and tramp elements.

Grain Size Control

In many alloys, certain constituents or elements tend to segregate preferentially in the grain boundaries. We can change the mechanical properties of the alloy by changing the grain-boundary strength or ductility. For example, sulphur contaminates iron-base alloys. To avoid an iron sulphide envelope around the grain boundaries, we add manganese to form a manganese sulphide. Nevertheless, ductility is reduced by this sulphide. The larger the grain size, the smaller the grain-boundary area. Therefore, for a given amount of sulphide present, the deleterious effect of sulphides increases with an increased grain size. (Similar analogies can be made for other alloys.)

Therefore, for identical physical properties, the grain size of the weld should be similar to that of the parent metal. Some newer techniques now include planishing the weld (working the metal) after welding, before heat treatment. This results in grain refinement and decreases physical discontinuities across the weld. A secondary method is to deposit the metal in the fine-grained structure. For example, a magnetostriction vibrator can increase nucleation of the molten pool during welding. Other more exotic methods involve nucleating agents similar to those used in making fine-grained castings.

Chemistry Control

As an example of analysis control, let's consider ordinary iron-base alloys. They contain

certain percentages of manganese, silicon, phosphorus and sulphur as normal impurities. Metallurgists, within a short period of time, have learned to minimize these. New melting practices, such as vacuum induction melting, no longer require that we tolerate large amounts of these elements. For good weld ductility, sulphur and phosphorus should be as low as possible. With the lower phosphorus content, we need less manganese to stabilize the sulphides. Silicon is not needed as a decarburizer. Therefore, a modified chemistry minimizing phosphorus and sulphur and re-evaluating the need for silicon and manganese is in order. It may be necessary to adjust other alloying elements to get mechanical properties equivalent to the original alloy. However, there is no doubt that both weldability and mechanical properties can be improved. Control of interstitials in titanium alloys is another example of improved chemistry.

Testing Procedures

The industry has used, for many years, a simple sheet metal tensile specimen with a weld perpendicular to the tensile axis. Unfortunately, much of the data collected from these specimens have been misinterpreted. A welded specimen like this from a material with 10% ductility may show a 5% ductility over a 2-in. gage length. "Conclusion: Weld ductility is poor". Such a statement is not necessarily true. For instance, in a sample where the weld is slightly stronger than the parent metal, yielding starts first on either side of the weld. After necking occurs, most yielding is concentrated near the area of neck. Such fracture in the parent metal bears no relation to weld ductility.

Now consider the same weld in which the weld metal is slightly weaker than the parent metal. Yielding starts in the weld metal; because of the initial necking action, most deformation is concentrated in this area. In effect, the gage length has been reduced to approximately the width of the weld. Increment elongation measurements have revealed as high as 30% elongation in such areas, where the 2-in. gage length ductility was only 5%.

Ideally, the best weld would be a butt joint without physical discontinuities. Mechanical properties across this joint would be uniform. Since full-scale testing is both expensive and time consuming, we need a simple inexpensive test which will allow the materials engineer to narrow the choice of materials down to a minimum. No one test can do this job. On the other hand, the three sample tests being proposed can do an excellent job of initial evaluation of materials.

For a given material, we should have three sheet metal tensile specimens. One will be of parent metal, the second, a welded specimen with the weld perpendicular to the tensile axis, and the third, a welded specimen with the weld parallel to the tensile axis. All are shown in Fig. 7. The first sample will give the basic uniaxial loading capabilities of the material. The second and third specimens must have all weld reinforcement removed before testing. The second sample will give the approximate relationship between the yield strength of the weld metal and the parent metal. (We say "approximate" because if the weld metal strength exceeds the parent metal, the parent metal failure will not show you the true yield strength of the weld metal.) The third will demonstrate the compatibility of the stress-strain relationships of the weld metal, the parent metal, and the heat-affected zone.

If all three of these specimens show almost the same modulus, yield strength, tensile strength and ductility (as measured by elongation), you can be reasonably sure that mechanical properties are fairly homogeneous across this joint. If they differ, an analysis of this difference will help in determining ways to improve the weld, or will dictate the limitations of the material or welding process.

This series of tests, coupled with a simple notch tensile test, can do much toward minimizing the testing cost prior to full-scale testing. Although extensive bi-axial stresses are not imposed, the simulated bi-axial stress in the notched specimen and in the longitudinal welded specimen aid in predicting its bi-axial response.

Summary

The major contribution that can be made by the metallurgist is in the field of improved weld joints and in fresh approaches to better strength. He can contribute much to these and other problems by forgetting past experiences when they tend to restrict his imagination. This is no field for a conservative thinker. Few things are impossible but progress can be inhibited severely by assuming that standard practices cannot be bettered. Astronauts are dreaming of outer space; the metallurgist should begin to do some dreaming, too.

Metals Used in the Vanguard

*By CHARLES HIRST**

Stainless steel, aluminum and magnesium alloys, and titanium are employed in various areas of the vehicle. Future missiles will benefit from the evaluation of materials for this application. (T24e, 17-57; SS, Al, Mg, Ti)

BASIC DESIGN PARAMETERS of lightness and high strength at elevated temperatures with good ductility at liquid-oxygen temperatures led to the use of a variety of metals in the construction of the Vanguard vehicle.

Titanium was the choice for the nose-cone tip. It is used because it provides a good heat sink for temperatures as high as 1500° F. arising from aerodynamic heating. Just behind the titanium nose-cone tip is the nose cone itself. Constructed of phenolic impregnated asbestos (Pyrotex, style 41-RPD), it opens like a clam shell and is dropped shortly after the second stage ignites. Its main purpose is to prevent aerodynamic heating of the satellite during the upward flight of the vehicle through the atmosphere. Thus, it must be able to retain its strength up to 900° F. and must possess high emissivity to keep the satellite cool.

Airframe Uses Light Alloys

The section below the nose cone is the airframe which houses the third-stage rocket and the equipment bay, which is the heart of the entire vehicle. The guidance and altitude reference systems are located in this area just ahead of the second-stage propellant tanks. A magnesium-thorium alloy, HK-31, is used as skins in this area because of its favorable strength-to-weight ratio up to 600° F. Internal frames and longerons are made of aluminum.

The second-stage propellant tankage is fabricated from Type 410 stainless steel. It was chosen because of its weldability, resistance to corrosion from the second-stage propellants and the ability to heat treat it to high strength. The tankage is constructed so that the tank walls also form the missile's structural skin. The integral tankage consists of a fuel tank and oxidizer tank separated by a helium sphere. The welding method used throughout is the inert-gas-shielded tungsten-arc process. Manual welding is employed for all except the longitudinal seams on the oxidizer and fuel tanks, where machine welding is used.

Heat Treating Tank Domes

Domes for the tanks are fabricated in a five-step drawing and annealing operation. Annealing these hemispherical heads for the fuel and oxidizer tanks is a critical heat treat job. The chief problem is carbon pickup by 410 stainless which increases hardness and causes brittleness in the finished part. To avoid this, heads are annealed at 1625° F. in a pit-type furnace which is completely free from carbonaceous materials and is tight enough to prevent excessive scaling.

Final hardening of the welded tank assembly is another critical heat treat operation. The heat treating range is between 1750 and 1850° F.

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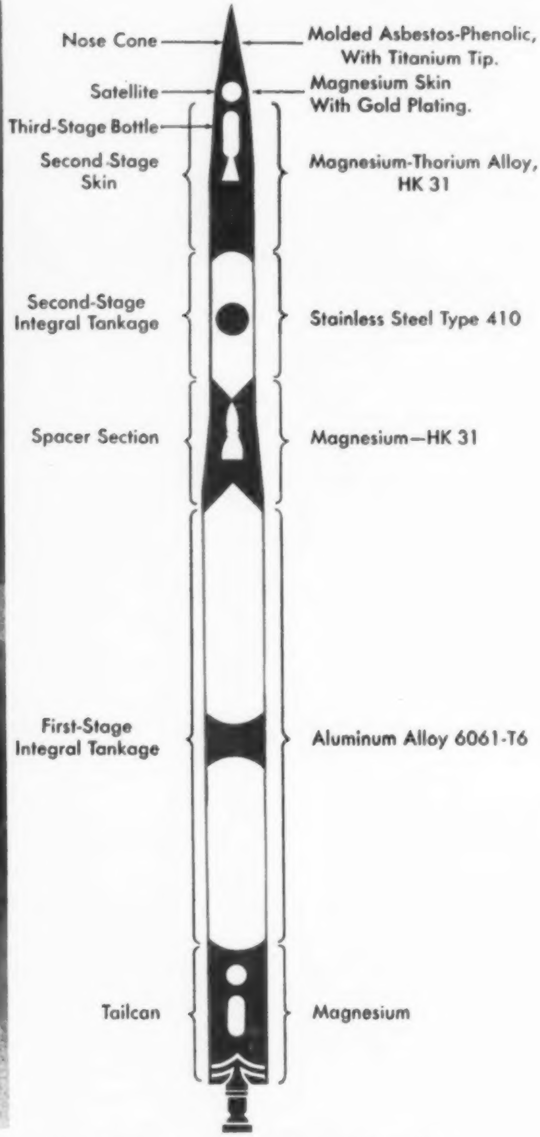


Fig. 1 – Rising Slowly From Its Launch Stand, the Vanguard Rocket Begins a Test Flight. This test proved the aerodynamic soundness of the finless research rocket. At right, materials used in the Vanguard. Over-all length of the vehicle is 72 ft.

This is followed by air quenching and final tempering at 600° F. Objective is to bring the yield strength of 410 stainless to the highest obtainable value and retain good resistance to stress-corrosion cracking. A 20-ft. vertical furnace of bottom-opening type, supplied with an exothermic atmosphere, is used. The interior of the tankage during this operation is continually purged with dry argon to prevent excessive scaling. Upon completion of heat treatment, the tankage is descaled in a two step process: The first step conditions the scale using a caustic-permanganate solution at 200° F. for 30 min. This is followed by a pickling in 1 *N* solution of inhibited nitric acid at room temperature for 3 hr. The completed tankage is tested hydrostatically using a pressure of 1.1 times the maximum operating pressure.

First-Stage Tanks

The transition section and the aft skirt are fabricated from magnesium-thorium alloy, HK-31. Its high strength at elevated temperatures and its lightness were determining factors in its use. Behind this transition section lie the first-stage tanks. As was noted before, these integral tanks are also constructed so their walls form the missile's outer skin. The tanks are built of an outer skin, internal frames, end frames and domes. Aluminum alloy 6061-T 6 is used. It was chosen because of its weldability and ductility at liquid-oxygen temperatures (−350° F.). In addition, it also has good strength for buckling loads. Both spot welding and fusion welding are employed. Spot welds are used to provide structural integrity; fusion welding gives both structural integrity and sealing.

The domes of the tanks are Marformed (see p. 77) and have scalloped edges to provide more inches of welding in a given distance. A scalloped doubler is spot welded to the dome to compensate for the heat-affected zone of fusion welding. After fabrication, tanks are hydrostatically tested. Primary leaks are repaired by

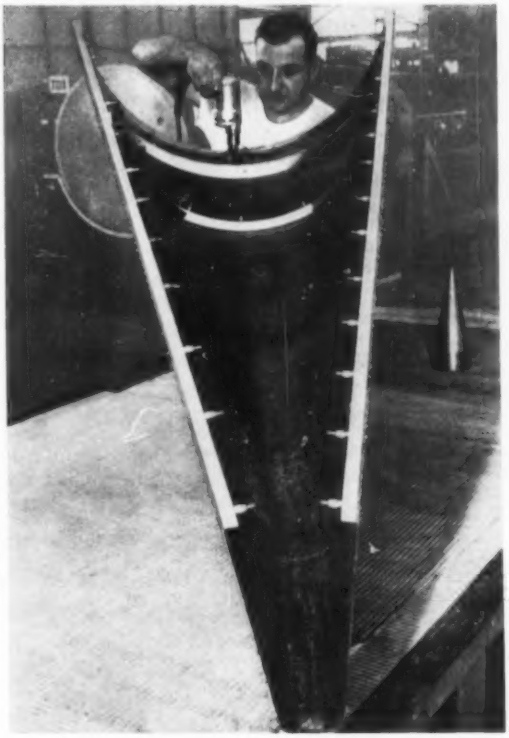


Fig. 2 – Half-Shell of Vanguard Nose Cone With Titanium Tip in Background. Nose cone is constructed of phenolic impregnated asbestos

Fig. 3 – View of Second Stage of the Vanguard. Workers are examining the "brains" of the missile located near the nose cone end

welding. The tanks are then cleaned with a chromic-sulphuric acid solution and dried.

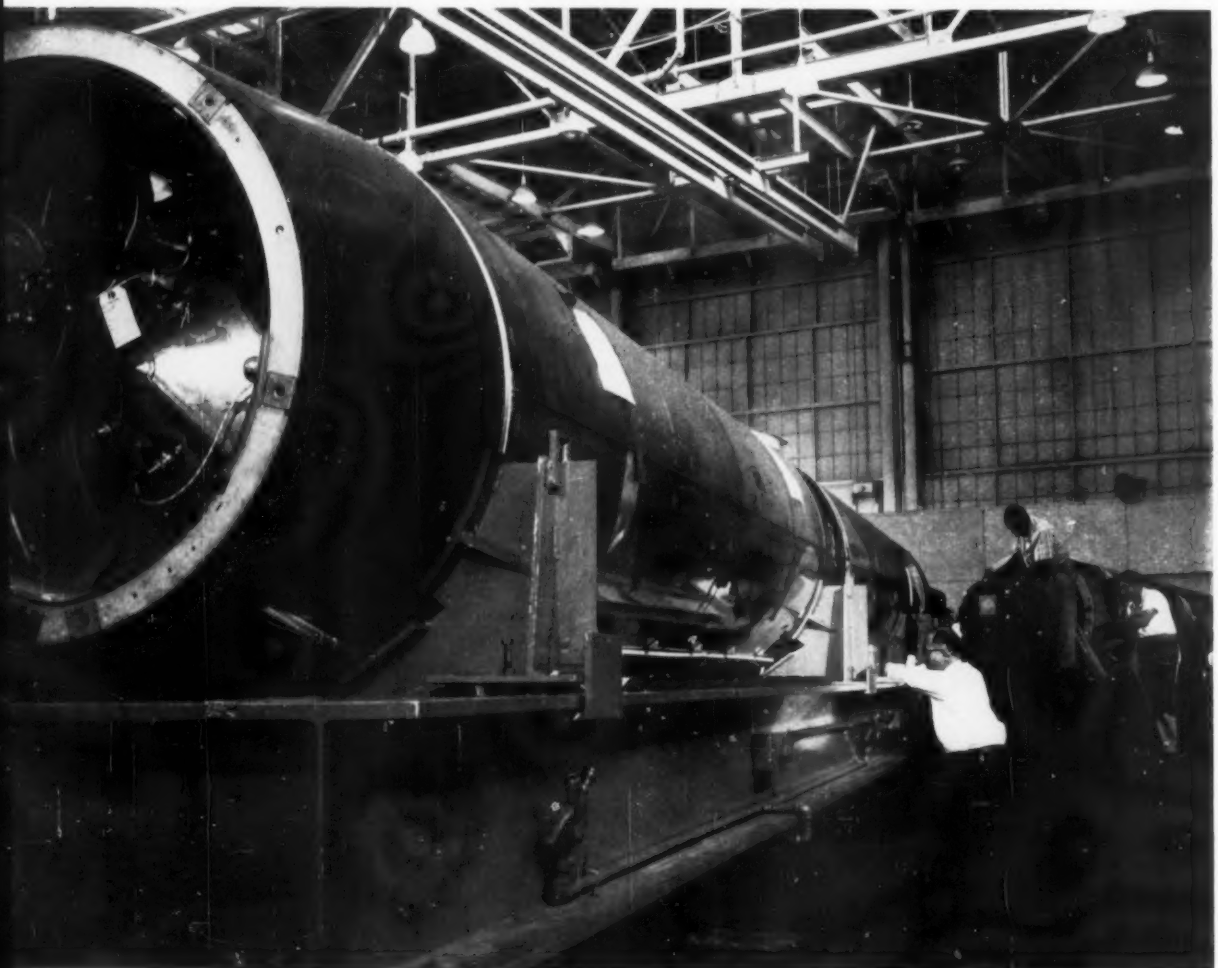
Tanks to hold hydrogen peroxide and tanks for propane are also made of 6061-T 6 alloy. Parts for these tanks are chemically milled to the desired thickness and then fusion welded. They are then chemically cleaned with a chromic sulphuric acid solution, then flushed and dried. The peroxide tanks are subsequently passivated with a solution containing 30% hydrogen peroxide.

Future Missiles Will Benefit

Special metals or alloys are used in many other areas of the vehicles. An example is the roll jets on the first stage where high-pressure steam is used. For this application, titanium was chosen for the bellows because of its lightness and the fact that it retains strength on prolonged exposure to elevated temperatures.

To achieve maximum performance, materials which are uniquely suited for specific applications must be selected. This, we believe, has been accomplished in the Vanguard vehicle. However, evaluation of the suitability of materials is a continuing function. It is felt that the Vanguard vehicle will contribute significantly toward the compilation of information on materials needed to increase the performance of future missiles.

Fig. 4 – The 45-Ft. Long First Stage of the Vanguard Three-Stage Rocket Is Shown on Its Dolly. Major portion of the first-stage tankage is constructed of aluminum sprayed with a plastic cover. The first-stage engine of another rocket is in the background



Fabricating Sheet Metal for Aircraft

*By ADOLPH VLCEK, JR.**

Aircraft and missile manufacture is sparking a revolution in sheet metal fabricating. Routine forming and joining methods formerly used are being replaced with techniques designed to handle the high-strength alloys needed for our supersonic aircraft. (G14, G-general, F22, J-general, K-general, T24)

SHEET METAL FABRICATION in the aircraft industry, by necessity, departs in many respects from established sheet metal processing and planning techniques employed in other industries. When sheet metal was first adopted for airframe construction, no specialized processing machinery was available for it. We had to improvise. In adapting our available equipment for the job, component parts of an assembly had to be fabricated in many bits and pieces.

One of the first significant improvements was the introduction of sheet metal stretch forming equipment. Familiar to most of us today, this machinery can stretch-wrap large sheet metal panels and extruded details such as longerons, stringers and circular frame members.

Another important development was the Guerin trapped rubber forming system. The rubber head, which is confined in a round or rectangular steel frame, serves as a portion of a tool such as the lower half of a conventional die. When the ram descends, the pre-positioned material and tool are impressed into the rubber head, and any flanges extending beyond the outline of the tool are pressed around and into the tool proper. Since only the punch portion of a conventional die is required, close tolerance machining necessary for mating precision dies is eliminated, with tremendous savings in tool cost.

However, this process still makes it necessary to hand finish parts. Efforts to minimize this undesirable operation led to the development of Marform, a refinement of the Guerin process. Marform retains the economies of the trapped rubber head, but to it has been added a hydraulically actuated pressure pad. This controls the flow of material over the tool and produces formed parts that previously were attainable only with costly, complex steel dies. Marforming has made it possible to reduce our costly hand finish form effort by more than 69%. Other versions of this forming principle are Hy-Draw and Hydroforming.

Hammer Forming

Our overworked drop and Yoder hammers have been and will continue to be used to form complex-shaped aircraft parts. Forging provides economies in tooling and production and is particularly suited to the forming of elbows, exhaust stacks, shrouds, nacelles and other parts with complex contours. Yoder hammers are frequently used for prototype forming of large sheets or skins with compound curves, and can also be used to correct minor discrepancies in parts formed by other methods.

Another technique, used quite extensively in the airframe industry, is bulge forming. This method is particularly adaptable to large cylindrical or circular sections such as engine nacelles.

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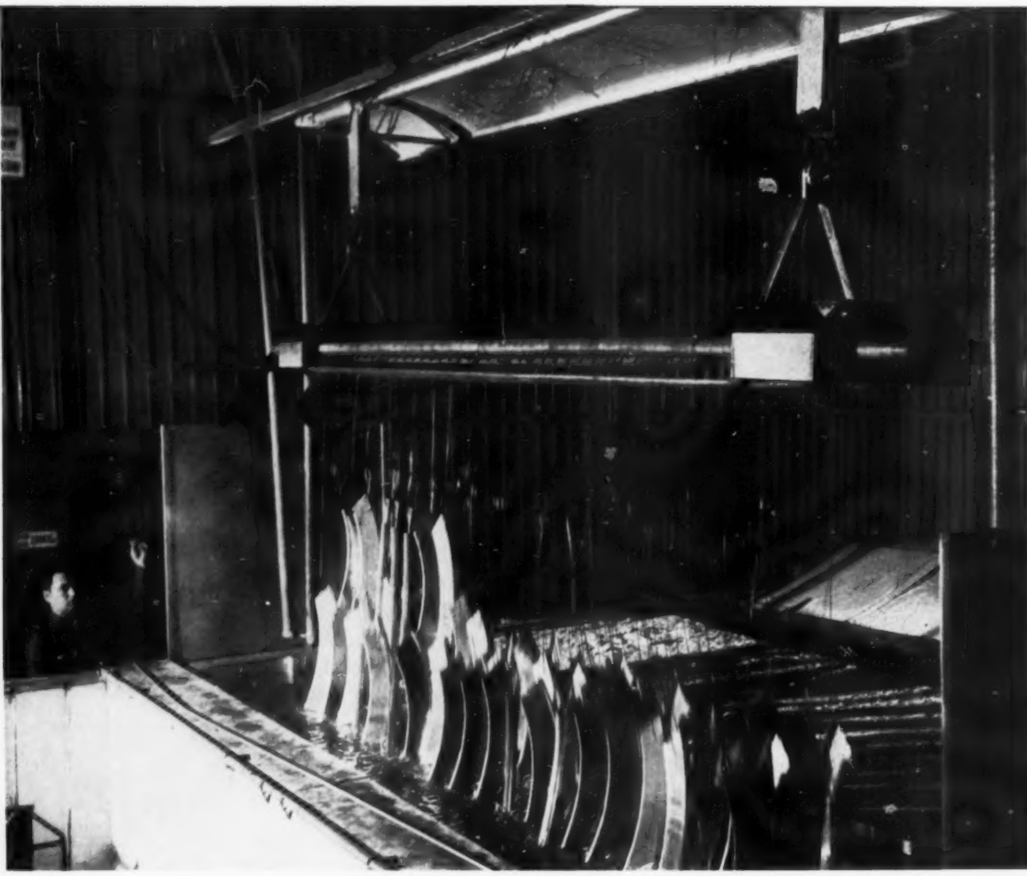


Fig. 1 – "Free Fall" Method for Quenching Aircraft Parts. Hooks in the fixture above are released dropping the parts into the tank

Several different versions exist; they employ hydraulically expanding dies, compressed rubber and, very recently, explosives.

Other versatile machine tools used in airframe sheet metal forming are slip rolls, brakes, mechanical presses, foot, hand and hydraulic shrinkers and stretchers. Metal spinning is also being used to some extent; however, this process has been supplemented with another known to us as flow turning. The latter holds considerable promise for more extensive use in airframe sheet metal fabrication. Tubing, which is also used extensively in our operations, is processed on standard equipment for bending, flaring, swaging and beading.

Heat is often necessary to perform many of these operations. Elevated-temperature forming and shaping of parts has been prompted in recent years by designs calling for parts to be fabricated from the newer materials such as titanium, zirconium and hot work die steels. These stronger materials are often too stiff to be cold formed.

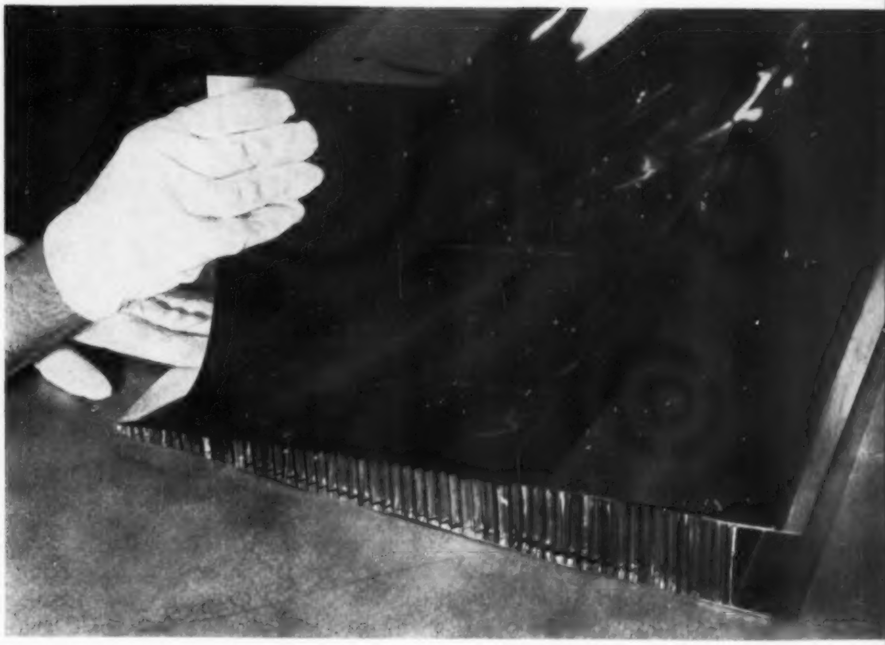
Sheet metal blanks are normally produced by routing and sawing. Where large production justifies the expense, we resort to the pierce blank templet-type dies. On higher tensile materials, such as titanium and stainless steel alloys, we employ conventional punch and die sets and specially designed steel rule dies.

Drilling operations are performed on parts stacked to various predetermined heights, depending on the material, gages, and drill runout allowance. Matched and tooling holes are drilled from fixed bushings mounted in drill templets. Stack heights are limited on the latter to control drill runout and center-to-center hole tolerances. Stack heights must also be controlled when drilling titanium, stainless steel and other high-tensile materials.

When severe contours or sharp bend radii are required in aluminum, we usually form annealed material, and follow with heat treating and hand finishing. Not all such material, however, is processed in the annealed condition; practically all other aluminum sheet metal parts are made from fully heat treated material.

When heat treating is needed after forming, we use both the oven and solution heat treating processes. At Martin, much quenching is done in salt baths; however, we have departed from the basket-type quench which produced a considerable amount of distortion in the aluminum

Fig. 2 – Assembling a Honeycomb Panel at Martin



parts. We now use a system known as "free fall". Instead of loading and lowering a basket into the quenching medium, we hang parts to hooks positioned on a rack. After removal from the salt bath, a quick release mechanism is tripped just above the quenching tank, dropping parts into the quench. Figure 1 illustrates the action. This technique provides a faster, more uniform quench producing relatively distortion-free parts.

Joining Techniques

In sheet metal joining, riveting and fusion welding have long been standard, but with the general acceptance of the sandwich materials with their high strength-to-weight ratio, adhesive bonding, brazing and "cold' 'welding are leaping into prominence. The intricate assembly of fusion welded or riveted structures, with its complex assembly fixturing, has been replaced to some extent by relatively simple, highly efficient and economically produced adhesive-bonded honeycomb structures. Figure 2 shows a honeycomb panel being assembled. Where operational temperatures are high, adhesive bonding is being replaced by brazed structures; while the brazing art has not progressed to the degree of perfection currently enjoyed by adhesive bonding, it is anticipated that this gap will be narrowed rapidly. Future models, in the predesign stages, indicate that brazing is only an interim method of metal joining. To produce these models successfully, it will be necessary to modify present resistance welding techniques and equipment. One of the principal problems to be overcome is the welding of thick cover skins to relatively thin core materials without increasing the notch sensitivity of high-strength parent materials.

The Future

Let's take a brief look into the immediate future – the production of weapons systems for operation within the next five or ten years.

The rapid transition to high-speed, high-performance missiles and space vehicles presents us with a challenge equal to none in our history. New exotic sheet materials, capable of retaining their full strength and anti-erosion characteristics at extremely high speeds, will require revolutionary changes in our processing methods. In many instances, materials have yet to be developed to withstand the severe operational conditions. Consequently, there is little or no processing know-how to rely on in converting them into usable items. For this reason our industry is expending more and more effort in manufacturing research and development – an effort devoted almost exclusively to the resolution of these problems. With reliable materials and processing methods, the future of these high-performance vehicles is assured.

Ultrasonic Testing at Douglas

By W. C. HITT*

Internal soundness and good bonds are essential in forgings and honeycomb panels for today's aircraft. Improvements in ultrasonic testing methods help the producer of components to maintain quality at all times. (S13g, T24)

THERE ARE SEVERAL avenues to follow in making ultrasonic tests on parts or raw material. For example, when we test the forging shown in Fig. 1, we must consider several important points. For one thing, forgings of this size are subject to difficulties which would not be encountered in smaller forgings. Suppose that the material used for this forging had been used for ten smaller forgings. In these ten you might find indications that could cause one or two to be rejected. Using the standards generally applicable to present-day Class "A" zoned forgings, we might be able to salvage one of these; the other would be rejected.

*Assistant Chief, Quality Control, Santa Monica Div., Douglas Aircraft Co., Santa Monica, Calif.

Fig. 1 – Large Forging for Aircraft. This 580-lb. piece is reduced to 370 lb. when all machining is completed. (Courtesy Douglas Aircraft Co.)

Our problem now is that the material that formerly made several smaller forgings now makes one large one. Applying the same standards, we would not expect to get a good forging, since there is a greater opportunity for indications to appear in the larger mass of material. Before ordering forgings of this size, subject to ultrasonic inspection, the user, the fabricator, and the raw material supplier must agree on specifications to be followed.

Agree on What Is Needed – First, we would study this 580-lb. forging and find that it is reduced to about 370 lb. after final machining. Removal of the 210 lb. of excess metal will take care of some ultrasonic indications providing the operator can plot the flaw locations accurately. Also, forgings of this type may have lightly loaded zones which "Engineering" may classify as Class B or C areas.

Discontinuities of about 1/8 in. diameter (or equivalent cross-sectional areas) are allowable in Class C areas, provided they do not come to the surface or near it. Discontinuities in other areas should only be considered flaws when their location, in relation to the applied stresses, would be detrimental.

Once the forging has been classified by zoning, we negotiate with the vendor to obtain forgings that will meet the established requirements. This method provides enough data so that vendors and purchasers can intelligently discuss price and delivery.

The next area of difficulty is in interpreting specifications. Most aircraft ultrasonic testing specifications go into considerable detail as to how the job will be done. As you know, there is more than one way to skin a cat – to use your method may cost the vendor extra time, and you would pay more for the part. A survey to determine the vendor's integrity and ability to do the job may be better than imposing detailed inspection instructions which he may not be able to follow. In either instance, you are only guaranteed that, if flaws found later make the part rejectable, the raw material will be replaced.

Effects of Variables

Considerable research has been done to determine the effects of variables on ultrasonic testing. For example, to resolve the effect of grain direction on signal response, three sets of test blocks were cut from hand forged 7075, 2014 and 7079 aluminum. One set of each alloy was cut in the short transverse direction, the second set in the long transverse direction, and the third in the longitudinal grain direction. These three sets of blocks were tested at all available frequencies up to 25 megacycles, using both contact and immersed methods, and both quartz and lithium sulphate crystals. No appreciable difference was noted in response between sets with different grain directions at lower frequencies. Above 10 megacycles, there is an effect noticeable when testing the longer blocks. These tests established that test blocks made from either rolled or forged aluminum may be used to compare flaw sizes regardless of the grain direction. This is true when normal test frequencies are used, or where higher frequencies are used for thinner materials.

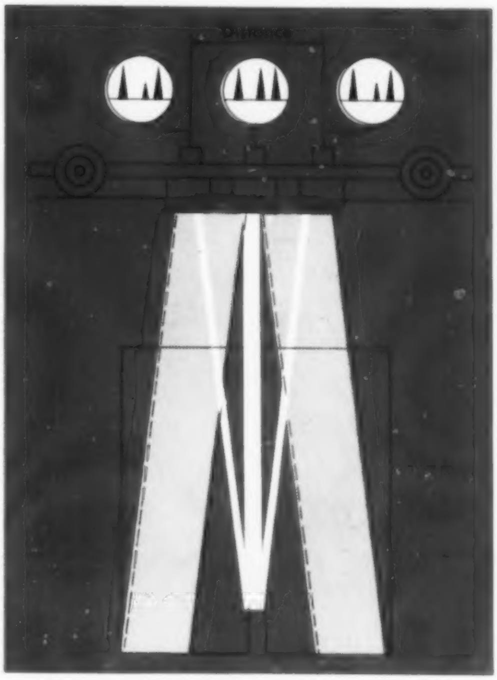


Fig. 2 – Diagram Showing Effect of Sonic Beam Spread on Indicated Length of Flaw. (Except where noted this and other illustrations courtesy Ultrasonic Testing & Research Laboratory)

The effect of heat treatment on signal response has also received attention. A series of tests were conducted on 7075, 2024, 2014 and 7079 aluminum alloys at frequencies up to and including 10 megacycles. No appreciable effect was noted. The sets of test blocks were compared in the F, annealed, T-4, and T-6 condition except for the 2024 which was in the T-3

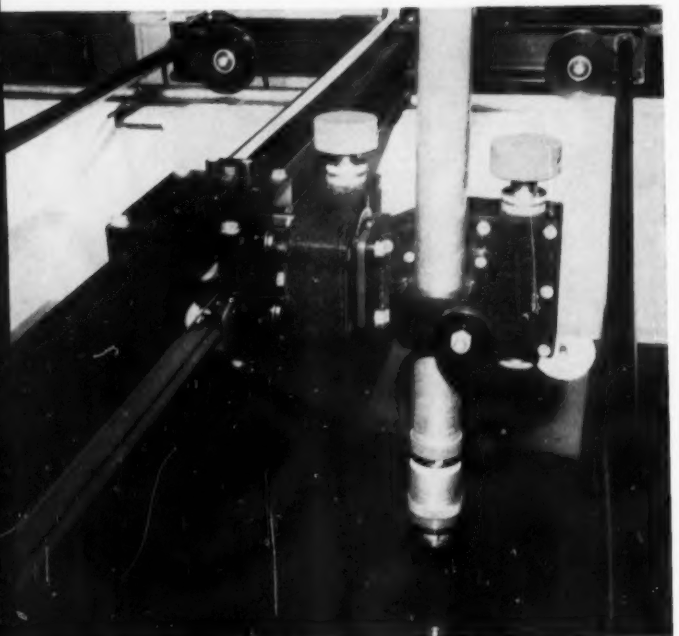


Fig. 3 – Manipulator for Precise Location of Flaws Has a 40:1 Gear Ratio

Fig. 4 – Test Forging With Simulated Flaws for Training Operators. It is lying in the ultrasonic testing unit

condition. At 15 and 25 megacycles, a variation in response was observed in the longer blocks.

A complete study of these and many other variables* was made by Ultrasonic Testing & Research Laboratory under a Wright Air Development Center contract. Titanium and magnesium alloys were also included.

Measuring Flaws

Determining the area of relatively smooth surfaced discontinuities is easily done; the signal response from the flaw is compared with the signal from a flat-bottomed hole in a conventional test block. (Flaws with irregular surfaces will generally be larger than indicated.) When a flaw has some width or length (as has a stringer), the flaw signal remains peaked on the scope while the crystal is moved along the flaw.

The technique for measuring flaw dimensions is illustrated in Fig. 2. You will note that the distance traveled by the crystal does not necessarily represent the length of the flaw; sound waves from the crystal form a cone-shaped beam which may vary in width (beam spread). The following factors affect the spread:

1. Crystal frequency.
2. Crystal diameter.
3. Crystal type (barium titanate, quartz, lithium sulphate, or the new Z-type ceramics).
4. Amplifier gain.
5. Distance from crystal to flaw.

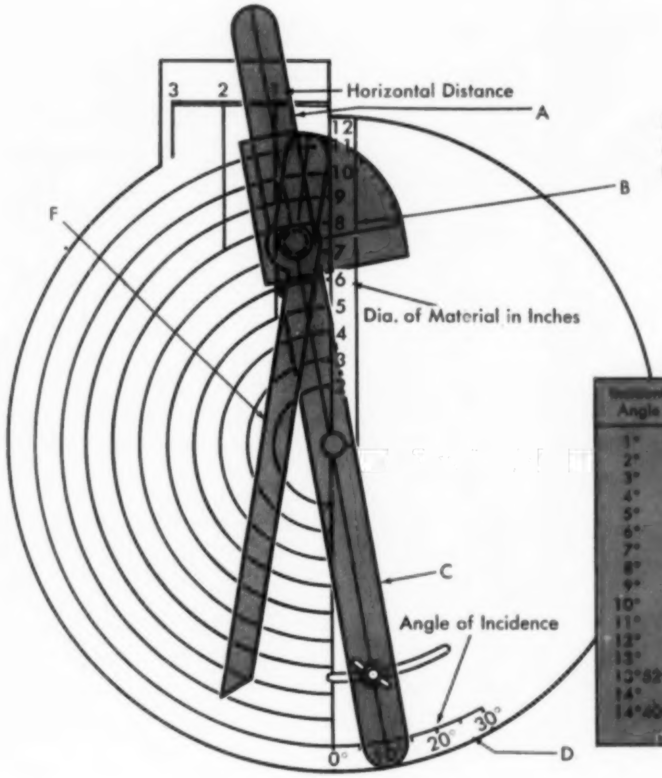
When all but one of these five factors is increased, the beam spread increases; increasing the crystal frequency diminishes the beam spread, and thus reduces the crystal travel.

Two types of gages are used to calibrate the testers; they enable determination of length and width of flaws. Type 104-1 slot blocks have slot widths from 1/64 to ½ in. and may be used for flaw width or length evaluation. These blocks are all the same length with the slot 1½ in. from the top of the block. The 104-2's are 3¼ in. face-to-slot, and the 104-3's are 5¼ in. face-to-slot.

These three sets provide all the blocks necessary to evaluate flaws from 1/64 to ½ in. in width or length and will compensate for variables in material up to 7½ in. thick.

For flaws over ¼ in. long, type 104 A blocks are used. If a stringer-type flaw is over 1 in. long, the 104 B blocks are used. These blocks

*Technical Report No. 57-268 (A.S.T.I.A. Document No. AD 142034) is available from the office of Technical Services, U.S. Department of Commerce, Washington 25, D.C. This manual should be available at each ultrasonic installation and should be used by engineers and others concerned with testing.



Conversion Tables

	Aluminum		Steel	
Incident Angle	Longi-tudinal	Transverse	Longi-tudinal	Transverse
1°	4°10′	2°4′	3°57′	2°7′
2°	8°22′	4°8′	7°56′	4°14′
3°	12°36′	6°13′	11°56′	6°22′
4°	16°55′	8°18′	15°59′	8°30′
5°	21°19′	10°23′	20°8′	10°38′
6°	25°51′	12°29′	24°33′	12°48′
7°	30°32′	14°36′	28°46′	14°58′
8°	35°29′	16°44′	33°21′	17°9′
9°	40°46′	18°52′	38°10′	19°21′
10°	46°24′	21°3′	43°18′	21°35′
11°	52°43′	23°14′	48°54′	23°51′
12°	60°7′	25°28′	55°12′	26°8′
13°	69°44′	27°43′	62°41′	28°29′
13°52′	90°			
14°		30°2′	72°50′	30°50′
14°40′			90°	

Fig. 5 – This "Cylindricator" Helps to Determine Flaw Location. Its operation is described in detail in the text

only determine whether the stringer-type flaws were over the minimum length in the Ultrasonic Recommended Airframe Specification established by the Society for Nondestructive Testing. However, they will not tell you how much less than 1 in. the flaw might be. Generally, the 104 and 104 A sets are used by the aluminum and aircraft companies where a salvage may be made if the exact length and width were known.

A unit that will keep the scanning crystal parallel with the surface being tested has eliminated a major problem. Called a type 120 contour follower, it has been designed for inspection of warped or twisted plates and extrusions. This unit will scan to the edge and end of the material being inspected and has a scanning head on both ends of the carriage. A switching arrangement enables use of either or both crystals at the same time.

A simple and practical unit has been designed to inspect extrusions, bar stock, or plate up to 36 in. wide. This unit operates at speeds up to 1½ ft. per sec., and can also be manually operated by a lever motion. Its advantages are simplicity and low maintenance costs. Since it only uses one 110-v. wire, problems inherent in the use of long coaxial cables are eliminated.

For precision manipulation, the new manipulator shown in Fig. 3 provides the very fine adjustment needed. It is completely free of play, and the 40:1 gear reduction ratio makes it easy to position the crystal over the flaw.

Flash Line Flaws

Douglas and Alcoa both have procedures for locating and measuring flash line flaws. Ultrasonic Testing & Research Laboratory has been doing this for several years; it has developed a simple method. A test forging is employed which has several 3/64, 5/64 and ⅛-in. diameter test holes drilled at angles to place the flat bottom of the hole in a plane that follows the material flow path out through the flash line. This is used to develop the technique and train the operator to locate flaws in the flash line area by the shear wave technique. Figure 4 shows the test piece in the ultrasonic inspection unit.

Using the "Cylindricator" – Once the operator has found a flaw in the flash line or other areas, he must determine exactly where it is and know its size. This unit, shown in Fig. 5 – we call it a "cylindricator" – was made to assist the operator in correctly determining the flaw location.

The procedure for flaw location in a cylindrical-shaped part is as follows:

Measurement Technique

1. The crystal tube is positioned perpendicular to the nearest tangent point of the part being tested (centerline).

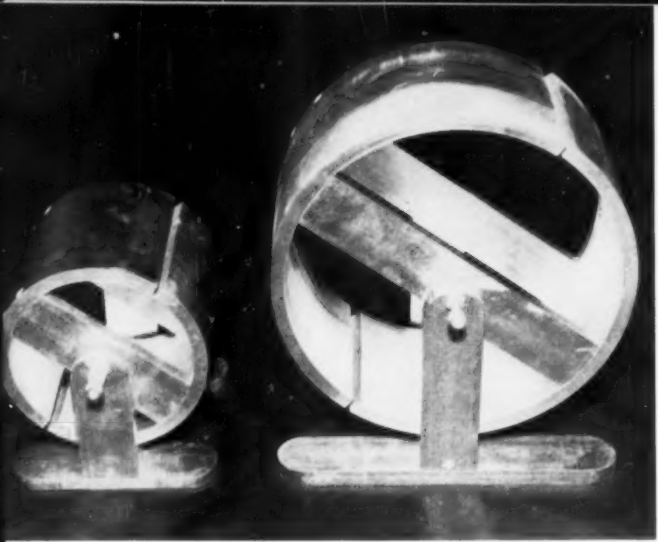


Fig. 6 – Shear Wave Reference Gages, Supplied in Various Diameters, May Be Used in Place of Drilling Test Holes in a Sample Forging

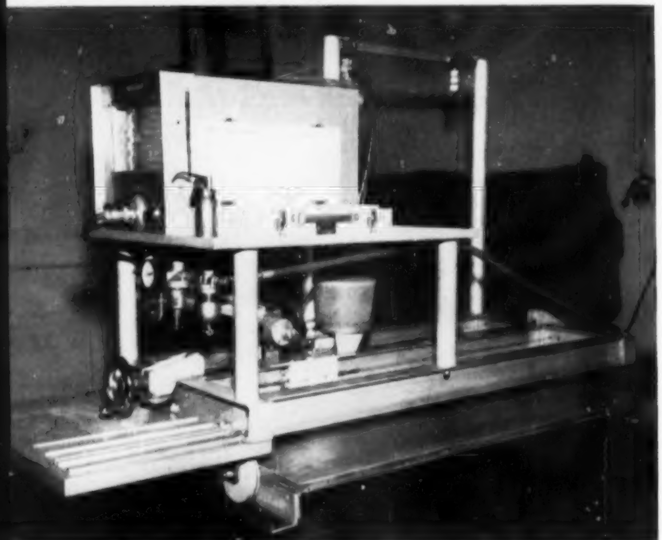


Fig. 7 – Bridge Assembly for Measuring Plate Thickness. This setup can measure a large area of plate in a short time

2. The sensitivity of the instrument is reduced, and the lateral crystal position adjusted until a peaking effect of either the front or back signal is noted.

3. This position is marked on the crystal carriage; it should be the center point.

4. The sensitivity is now increased and the crystal indexed (without changing the tube angle) until the defect signal appears.

5. The peaking point of the defect signal is found and the position of the crystal carriage marked.

When the distance between these two marked points, referred to as the "horizontal distance from centerline", is measured, the "cylindricator" can be set up.

Setting up the "Cylindricator"

1. The point is located on the calculator face where the horizontal distance from centerline (A) intersects the arc (B), designated in inches of diameter.

2. The angle indicator (C) is adjusted so that it also intersects the point (AB).

3. The angle indicator is locked with the thumb screw and the angle of incidence read at (D).

4. The corresponding refracted angle is found in table (E).

5. The refracted angle is set on protractor (F).

6. Protractor (F) is positioned so that the pivot point is superimposed over the point intersected by A, B, and C.

Reading the "Cylindricator"

The cylindricator is now set up to simulate test conditions. The ABC intersection represents the point where sound enters the part, and the indicator on the protractor (F) denotes the direction or path of sound. For a numerical value of the refracted angle in relation to the original vertical centerline, subtract the incident angle from the refracted angle.

The distance from point ABC to the defect can be determined by comparison with a standard reference block, or by the oscilloscope marker system. This provides graphically the location of the flaw. The flaw signal amplitude is com-

Fig. 8 – Sonic Chamber for Determining Bond Quality in Honeycomb Panels. Sand is spread over the panel; when vibrations are induced, the sand moves away from the unbonded areas. (Courtesy Douglas Aircraft Co.)

pared with a standard test block to determine the flaw size. Where the incident angle is greater than 4°, angle-type test blocks may be used for closer evaluation. New shear wave standard reference gages (Fig. 6) are now available; they may be used in place of drilling test holes in a sample forging.

These gages, supplied in various diameters and in aluminum, steel and magnesium alloys, improve accuracy of evaluating flash line defects.

Measuring Thickness

There have been some improvements in ultrasonic measuring. In measuring thickness, a portable oscilloscope-type resonance unit and a probe will measure a wing skin approximately 10 by 35 ft. in about a day. (A grid of 12-in. squares determines the measuring points.)

With the bridge assembly of Fig. 7 this time has been cut to less than 1 hr. The crystal is attached to an air cylinder operated from the work shelf in front of the carriage. A crank moves the crystal across the plate. The bridge itself moves lengthwise on ball bearing wheels. Indexing tapes provide the locating points. Up to 500 readings per hr. have been made with this testing unit.

Ultrasonic measuring is made simple and accurate by taper gages which can be used with any ultrasonic resonance measuring equipment. Taper gages give the operator more confidence in taking his readings, and simplify calibrating.

Testing Honeycomb

The sonic unit shown in Fig. 8 was devised by Douglas Aircraft Co. to inspect magnesium-covered paper honeycomb material. It is simply a sound chamber with two speakers mounted in each end. An oscillator and amplifier induce vibrations which range from 250 to 18,000 cycles per sec. The test panel is covered with sand and vibrated. The sand vibrates away from the unbonded areas and outlines them. Though fast and economical, this method is only practical for very light work.

Up to now, X-ray has been the most practical method of bond testing. Its drawbacks are slowness and an inability to reveal certain types of discontinuities. Adaptation of X-ray to image intensifiers and TV viewers is providing an additional test method adaptable to the detection of certain unfavorable bond conditions.

The latest development for testing metal-to-metal bonds and brazed honeycomb sections is the Sonograph shown in Fig. 9. This versatile method employs a conventional ultrasonic "scope", gating circuit, and oscilloscope tube to display the gate, plus a Hughes memory tube which pictures the lack of bond or flaw areas in the material under test. With the high-speed recorders being developed, this method will probably prove to be the most practical for bond testing. This instrument can also display the form and size of flaws in solid materials. The inset in Fig. 9 shows poorly bonded areas.

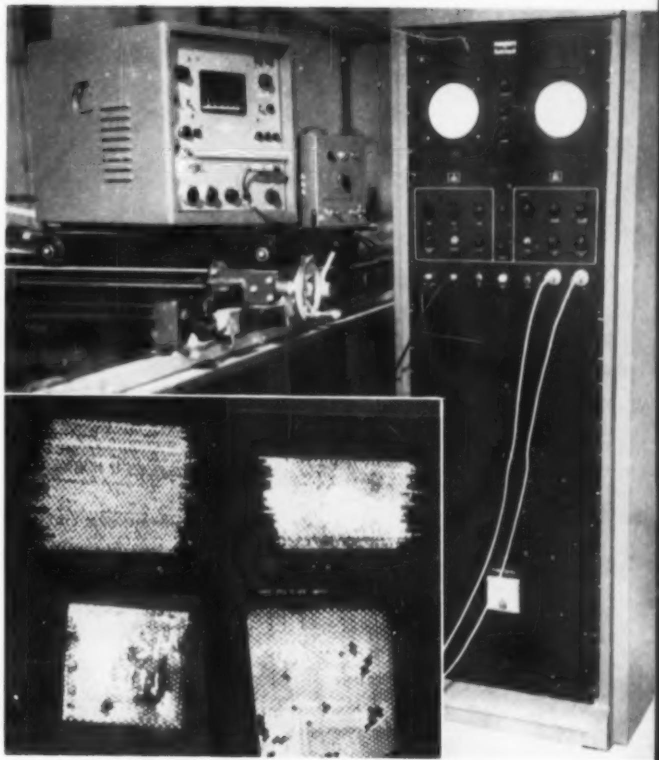
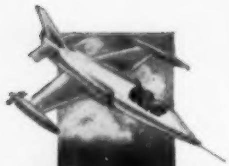


Fig. 9—"Sonograph" for Honeycomb Bond Testing. This machine reveals unbonded areas as shown in the inset

Another new technique is the "in motion" slit X-ray technique developed by Douglas. With it, welds in missile tanks can be X-rayed while the tank is in motion. Sixty feet of X-ray film can be exposed in the same length of time previously used to obtain 5 ft. of film.

These and other new methods all help to speed up the missile and aircraft program and to assure the highest degree of perfection obtainable. Constant efforts by both producer and user to improve testing techniques will insure further aircraft and missile development.



Coatings for the Supersonic Age

Ceramic Coatings for Insulation

*By ALAN V. LEVY**

Two types of coatings to withstand 3000° F. and above have been developed. One type is a flame-sprayed ceramic oxide; the other is a metal-reinforced ceramic which is applied by troweling a ramming mix into a metallic matrix attached to the structural base metal. (L27, 2-62)

ADVANCED POWER PLANTS for aircraft and missiles require protection of metal components in the combustion area of the engines at temperatures which extend ceramic materials considerably beyond the range of their previous applications. Frit-type ceramic enamels have had considerable use in reciprocating and turbojet engines. Generally, they are applied on components which contain hot combustion gases below 1800° F. (See *Metal Progress* for November 1958, p. 111.) Thicknesses of 0.001 to 0.002 in. are used. They extend the life of the component by protecting the metal against oxidation and carbon pickup. This type of ceramic coating has two shortcomings: One is its temperature limitation; another is its inability to insulate as well as protect the base metal.

Gas temperatures over 2000° F. require coatings which can withstand such temperatures and be applied in thicknesses sufficient to insulate the base metal structure from severe oxidation and strength reduction effects. Two types have been developed which have withstood temperatures of 3000° F. and above. In addition, they markedly reduce the operating temperature of the metal components upon which they are applied and withstand severe mechanical vibration of power-plant operation. The first of these insulating types of ceramic coatings to be used on a combustion chamber was a flame-sprayed ceramic oxide. The other was a metal-reinforced ceramic which is applied by troweling a ramming mix into a metallic matrix attached to the base metal.

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Unreinforced Coatings

Several ceramic materials have been successfully applied with an oxy-acetylene flame spray gun or a detonation device which propels the coating particles at the metal surface at high velocities. The following materials have been sprayed: alumina (Al_2O_3), zirconia (ZrO_2), mullite ($3\,Al_2O_3\cdot 2SiO_2$), forsterite (Mg_2SiO_4), zircon ($ZrSiO_4$), spinel ($MgO\cdot Al_2O_3$), chromia (Cr_2O_3), ceria (CeO_2), titania (TiO_2).

Thickness of the sprayed coatings varies with the application; generally it is 0.005 to 0.1 in. and greater in special cases. A practical thickness range for these materials is 0.005 to 0.080 in. for most applications. They range in porosity from

1 to 16% depending on the method of spraying and material used. The porous structure of flame-sprayed ceramic coatings gives them a mechanical flexibility that is several orders of magnitude greater than solid-body structures of the same materials. The surface of as-applied coatings ranges in smoothness from a root mean square of 10 to 250. Coatings can be ground to finishes of less than rms. 10 micro-inches.

Table I gives properties of ceramic coatings of this type either in production use or in the development stage. For the most part, coatings in use today are alumina and zirconia. Alumina is applied where its lower density is an advantage and where its lower melting temperature is not detrimental. Its low emissivity is also an advantage in combustion chambers and in other areas where high reflectivity is desired. Zirconia is favored where a material of higher melting temperature is needed, in rocket nozzles, for example. Figure 1 shows a ramjet engine tailpipe coated with alumina (Rokide A).

Flame-sprayed ceramics are in evaluation stage or are being used on production basis as thermal insulating and protective coatings in the following applications:

1. Ramjet engine combustion chambers.
2. Ramjet engine and afterburner combustor components.
3. Rocket thrust chambers and exit nozzles.
4. Jetevators (a thrust vectoring device for rocket engines).
5. Turbine wheels.
6. Burner tubes.

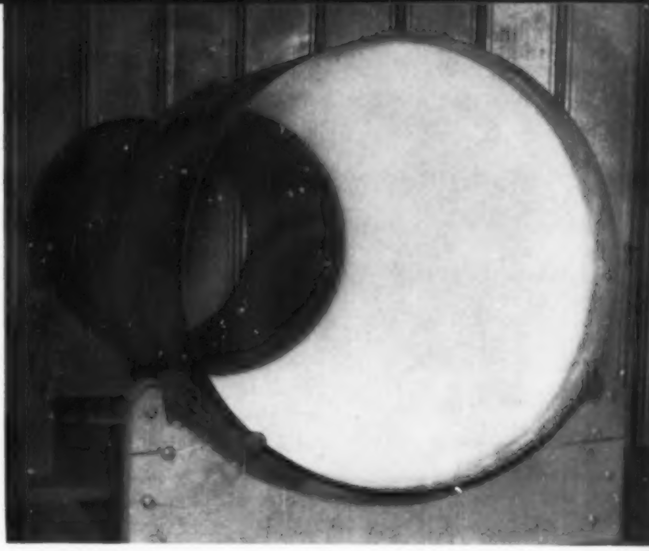

Fig. 1 – Ramjet Engine Tailpipe Coated With Flame-Sprayed Aluminum Oxide

7. Thermocouple tubes.
8. Inside surface of nose cone.
9. Fuel injectors.
10. Graphite boosters and sustainers.

Higher Temperature Coatings

The advent of higher heating sources such as the plasma jet will enable materials of greater refractoriness to be applied as coatings; this will extend the application range of flame-sprayed coatings. Coatings in the 4000 to 6000° F. range will be possible with the plasma jet flame.

Insulating ceramic coatings of the flame-sprayed type have certain limitations: (*a*) Maximum thickness is about 0.1 in. for economical, reliable service; (*b*) long-time multicycle service has not been absolutely proven, especially on sheet metal structures; (*c*) melting temperatures of the materials sprayed may inherently be too low; (*d*) the degree of insulation is determined by thermal conductivity and maximum thickness is limited.

Coatings of this type are in the advanced stages of laboratory development. Several types have evolved embodying many combinations of reinforcing medium and ceramic material. Various types and configurations of reinforcing media are being investigated:

- Wire mesh made from mild steel, 300 series stainless steel, and molybdenum.

Table I – Properties of Flame-Sprayed Ceramic Coatings

Property	Alumina (Rokide A)	Zirconia (Rokide Z)
Composition	98.6% Al_2O_3	98% ZrO_2
Density, lb. per cu.in.	0.115	0.187
Thermal drop through 0.030 in. at steady-state melting temperature	6° F. per 0.001 in.	8° F. per 0.001 in.
Maximum service temperature	3000° F.	4200° F.
Thermal conductivity*, Btu. per hr. per sq.ft. per in. per °F. at 1000 to 2000° F.	19	8
Emissivity, 1000 to 2000° F.	0.3 to 0.4	0.3 to 0.4
Thermal expansion coefficient, 70 to 2550° F.	43×10^{-7} per °F.	64×10^{-7} per °F.
Coating thickness range	0.005 to 0.100 in.	0.005 to 0.060 in.
Porosity	8 to 12%	8 to 12%
Hardness and abrasion resistance	Very high	High
Thermal shock resistance	Excellent	Good
Resistance to vibration and flexing	Very good	Good
Application cost per sq.in. per 0.001 in.	0.8 to 1.0¢	1½ to 2¢

*Calculated from thermal drop data.

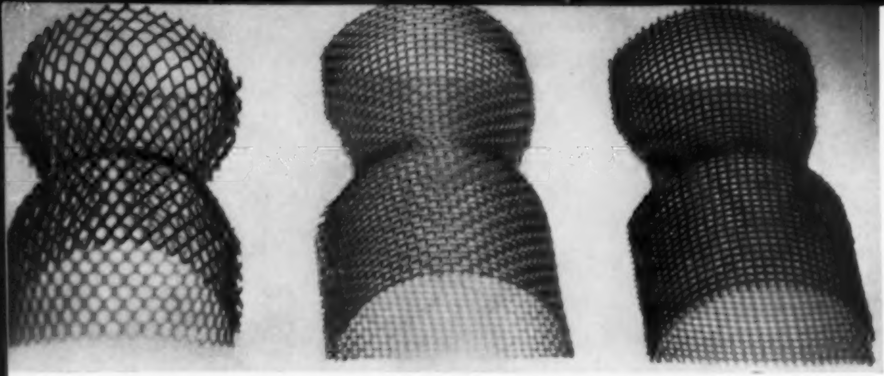

Fig. 2 – Rocket Nozzle Segments Formed From Expanded Steel, Type 304 Stainless Wire Mesh and Carbon Steel Mesh (Left to Right)

• Expanded metal made from mild steel, 300 series stainless steel, and molybdenum.

• Corrugated metal strips made from mild steel, 300 series stainless steel, and tantalum.

• Fibers of ceramic material, primarily aluminum silicate and quartz, or refractory metal randomly oriented in ceramic matrix and laminated throughout the matrix.

The types of ceramics being reinforced include: *(a)* sodium silicate-base composites containing various refractories, such as alumina, mullite, kyanite, silica; *(b)* phosphate-bonded alumina, zirconia and chromia; *(c)* pure alumina and zirconia.

Continuous network reinforcements such as wire mesh and expanded metal are required both to reinforce the coating and to provide a means of firmly anchoring the coating to the base metal. Figure 2 shows typical nozzle segments. They are brazed or resistance welded to the base metal prior to application of the ceramic coating.

Fiber metal and ceramic reinforcements are mixed into the ceramic mixture before application. When a molybdenum reinforcement is used, both it and the base metal can be coated for oxidation resistance before application of the insulating ceramic.

Ceramics are applied by two methods – flame spraying, for pure alumina and zirconia, and troweling, for the phosphates and silicates. In general, the reinforced ceramic materials now being studied do not require a high-temperature firing prior to service. Flame-spray coatings are used in the as-applied condition. Trowel coatings usually require a baking cycle at 800° F. or less. Figure 3 shows test panels and test cylinders of reinforced ceramics. Table II gives properties of two reinforced ceramic coatings.

Evaluation of Coatings

Reinforced ceramic coatings have been thoroughly flame tested in the laboratory in single and multicycle exposures. They are now undergoing tests to determine mechanical properties. They have been evaluated in combustion chambers of full-scale ramjet engines and show considerable promise.

Curves in Fig. 4 show how effective a reinforced ceramic coating is in providing thermal lag and steady-state temperature reduction in a panel of N-155. In this test, the oxy-acetylene

Fig. 3 – Test Parts Coated With Metal Reinforced Ceramic Compositions. Coatings will withstand temperatures in range 2500 to 4000° F.

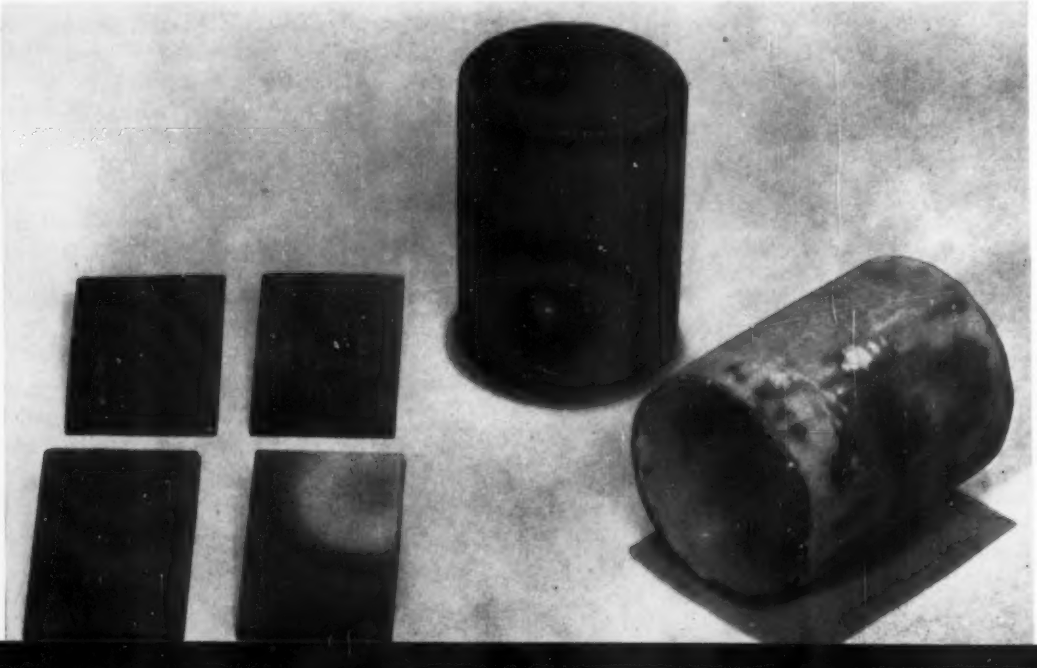

Table II – Properties of Reinforced Ceramic Coatings

Property	Aluminum Phosphate Bonded Alumina	Zirconium Phosphate Bonded Zirconia
Density of ceramic plus reinforcement	0.10 to 0.12 lb. per cu.in.	0.14 lb. per cu.in.
Thermal drop through 0.125 in. at steady state	8° F. per 0.001 in.	10° F. per 0.001 in.
Maximum service temperature	3500° F.	4000° F.
Thermal conductivity*, Btu. per hr. per sq.ft. per in. per °F. at 2400° F.	7.2	6.0
Emissivity at 3000° F. (may be modified by formulation change)	0.2	0.3 to 0.4
Reinforcement metal	Mild steel, stainless steel or molybdenum	Molybdenum
Curing temperature	800° F.	800° F.
Mechanical strength	Excellent	Good
Thermal shock resistance	Excellent	Excellent
Recycling capability	Excellent	Fair
Resistance to vibration and flexing	Excellent	Good
Coating thickness	0.1 to 1 in.	0.1 to 1 in.
Type of use	Coating or structure	Coating or structure
Material and fabrication cost	Low	Low

*Calculated from thermal drop data.

air torch was set to heat a bare panel of N-155, which was 0.050 in. thick, to 2100° F. in 30 sec. Using the same torch settings, panels coated with Rokide A, Rokide Z and reinforced ceramic were tested. It can be seen that a 0.035-in. coating of Rokide A (alumina) and Rokide Z (zirconia) provided a temperature lag of 400° F. for 30 sec. and reduced the steady-state temperature by 100° F. A reinforced ceramic coating 0.136 in. thick gave as much as a 1300° F. lag for up to 40 sec. and reduced the steady-state temperature of the metal by 500° F. (The gas temperature and heat flux used in this test were below those experienced in ramjet combustion chambers. Under operating conditions, especially for the higher heat fluxes, thermal insulation is even greater.)

Future – The present surface operating temperature maximum of 4000° F. will have to be extended to 5000° F. and above, if these coating systems are to keep up with some of the advanced power-plant concepts. The use of the plasma jet source for depositing higher melting materials, either in the form of full coatings or only as surface coatings over a lower melting material, should extend this type of coating to higher-temperature operation.

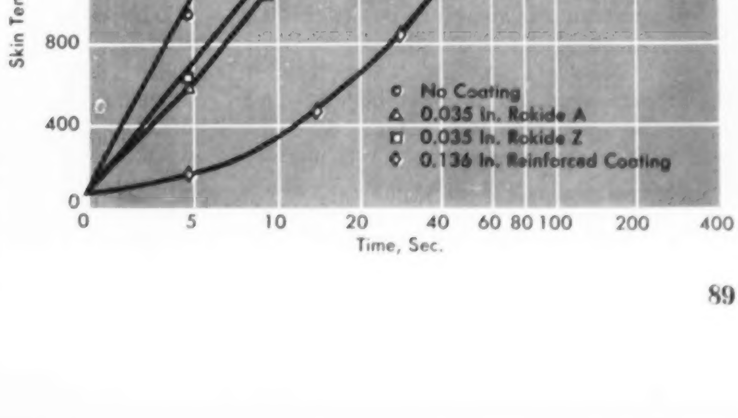

Fig. 4 – Curves Show Insulating Effect of Ceramic Coating on Transient and Steady-State Skin Temperatures of N-155 Alloy, 0.050 In. Thick

Fig. 1 – Regulus II Taking Off Assisted by Rocket. Corrosion and erosion problems encountered with this guided missile led to development of multilayer coatings

Coating for Re-Entry

By W. L. AVES*

A new concept in a laminated coating for high-temperature protection appears to have solved corrosion and erosion problems of re-entry into the atmosphere. Alternate layers of molybdenum and alumina provide excellent protection from rocket blasts at 4500° F. By varying thickness and constitution of the layers, many combinations, each with unique properties for a specific application, can be devised. (L23, L27; Mo, Al, 2-62)

ROCKETS used to augment a missile's engine during launching (such as shown in Fig. 1) often produce a 5000° F. blast. This intense heat is also accompanied by erosion of high velocity gases. Obviously, a material which will withstand these conditions must possess very unusual properties.

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To begin with, for aircraft safety (should there be an accidental ignition of the rocket motor) a similar blast must be contained under full burnout conditions. This is not easy. A typical test breech (Fig. 2) burns through in some 0.7 sec., even though it is constructed from 17-7 PH stainless steel, 0.125 in. thick, which is heat treated to 190,000 psi. and protected with 0.010 in. of alumina.

Since space limitation, weight, shape and fabrication all had to be considered, only one approach appeared practical. We decided that a protective coating or liner was required for the inside face of the breech dome, and began to test various materials at the Chance Vought Aircraft rocket facility.

To evaluate test domes, a breech was mounted to hold samples exposed to heat from a rocket motor, as shown in Fig. 3. This setup permitted full burnout of the rocket motor against the replaceable test domes.

At first, single-layer coatings were tried. The test domes were spun from 17-7 PH stainless steel (0.071 in. thick) and heat treated to tensile strength of 190,000 psi. Fabricators of coatings were then contacted for feasible liners. With the exception of a few high-priced liners ($1000 each), the more promising of these were tested.

When the first series of tests were performed using different materials as the protective coating or liner for the 17-7 PH dome, all coatings failed in less than 2 sec. under full burnout (Fig. 4). Table I gives pertinent data. From these tests, we concluded that the erosive blast, thermal shock, and temperature conditions were more severe than originally believed.

Multilayer Coating

Since single-layer coatings had failed so completely, we decided to try combinations. A multilayer coating (which subsequently proved successful) combined the erosion resistance and excellent bonding properties of molybdenum with the good thermal shock resistance and insulating properties of aluminum oxide. This metal-ceramic laminated coating is shown in Fig. 5. It was applied in varying thicknesses to three 17-7 PH test domes, which were 0.071 in. thick.

The history of each test (see Fig. 6) is outlined below:

1. Six layers of molybdenum (average thickness 0.002 in. per layer) were flame-sprayed alternately with five layers of alumina (average thick-

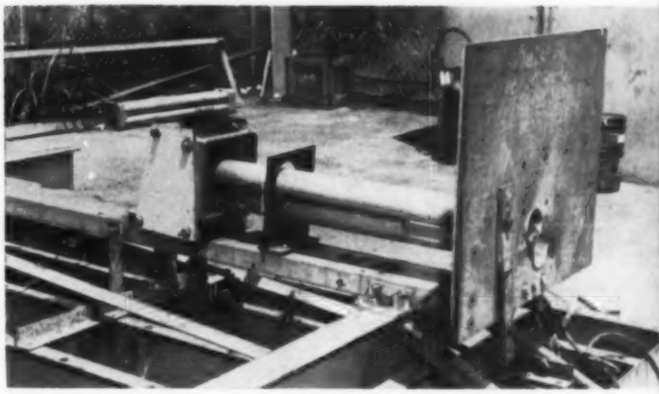


Fig. 3 – Rig for Testing Multilayer Coatings. The rocket propellant is held in the tube, and the test dome is positioned in the box at the rear

Fig. 2 – Test Breech for Sidewinder Rocket Showing Results of a Hangfire Test. Made of 17-7 PH stainless steel, this breech was protected by aluminum oxide

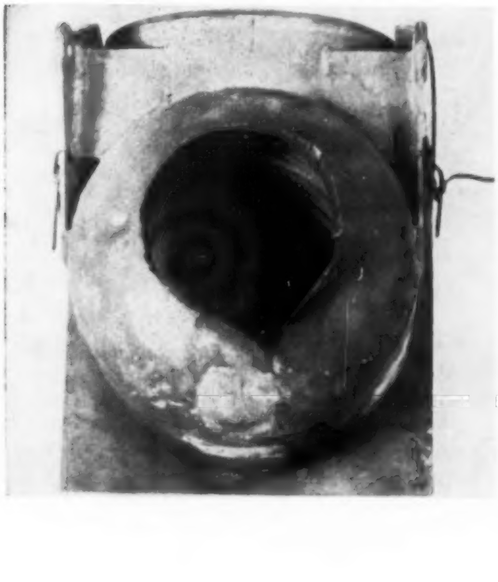
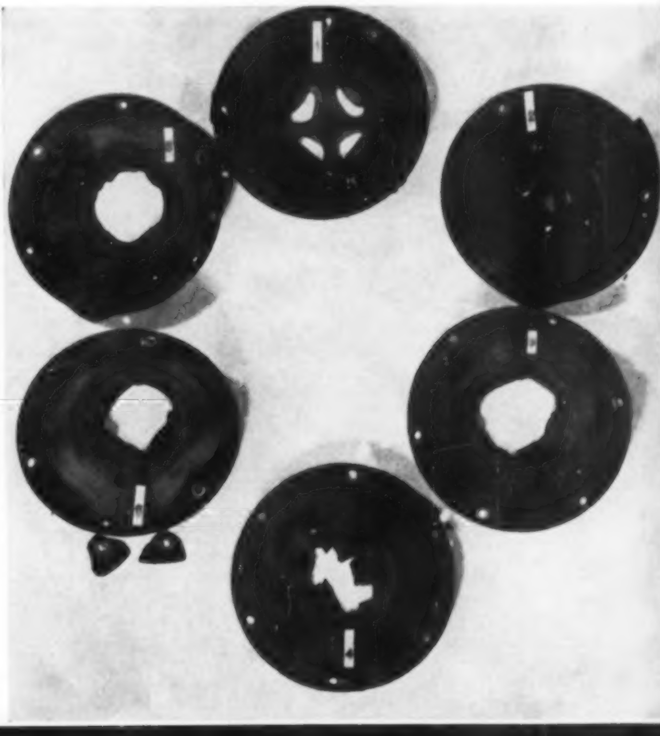


Fig. 4 – Initial Test Breech Liners After Testing Under Hangfire Conditions



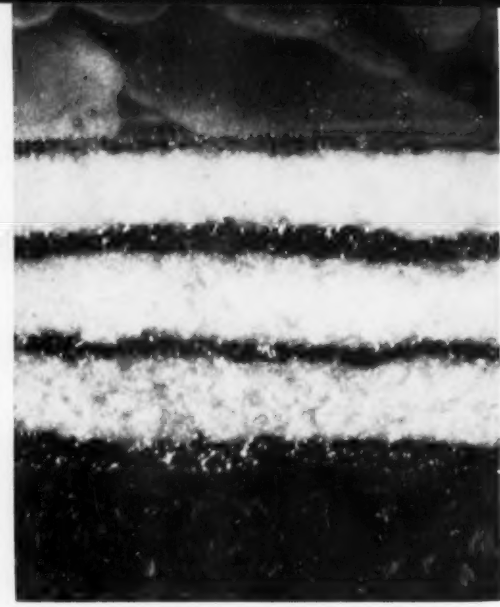


Fig. 5 – Multilayer Coating Cross Section. Four layers of molybdenum (dark) sandwich three layers of alumina (light)

ness 0.007 in. per layer). This resulted in a coating about 0.050 in. thick.

Results: Slight erosion of top layer of molybdenum with little additional impingement into secondary layer of alumina occurred. There was no perceptible spalling or poor adhesion.

2. A sheet of molybdenum 0.040 in. thick was spun to test-dome shape, trimmed to size, stress-relieved in a helium atmosphere, then electroplated with a chromium-nickel coating. It was attached to a 17-7 PH back-up plate coated with multilayers of molybdenum and alumina with total thickness of 0.015 in.

Results: Although the molybdenum liner shattered, the test dome did not burn through.

3. A glass-impregnated phenolic compound was molded ⅛ in. thick, and bonded to the concave surface of a 17-7 PH dome previously coated with thick (0.020 in.) multilayers of molybdenum and alumina.

Table I – Single-Layer Coatings

Test	Linear Material	Thickness	Time
1	X*	⅛ in.	1½ sec.
2	Y*	⅛	1¾
3	Cr	0.030	1
4	Mo	0.040†	1½
5	asbestos-impregnated silicone	⅛	1
6	none (control)	—	½

*These materials, believed to be silicates, bonded organically, were recommended for over 4500° F.

†Plated with 0.005 Cr and 0.001 Ni.

Results: The liner disintegrated, but the test dome did not burn through.

To establish the new coating's reliability, three additional domes were coated with the molybdenum-aluminum oxide lamination and tested under identical conditions. They did not burn through and exposed surfaces appeared only slightly affected. One test was subjected to a second full burnout blast with only negligible change. These three domes were then sandblasted to show a cross section of the laminations (Fig. 7). It can be seen that under these severe test conditions, the coating provided reliable resistance to both erosion and temperature.

Coating Characteristics

Some of the value of this coating is due to its insulating effect. As Fig. 8 illustrates, the temperature of a protected plate levels off at about 520° F. after 30 sec., while an unprotected plate burns through in 1 sec. under a full rocket blast. Although the actual thrust time of the solid-propellant rocket motor was 2 sec., excess fuel continued to burn for about a minute longer at a greatly reduced temperature.

A big factor contributing to the excellent insu-

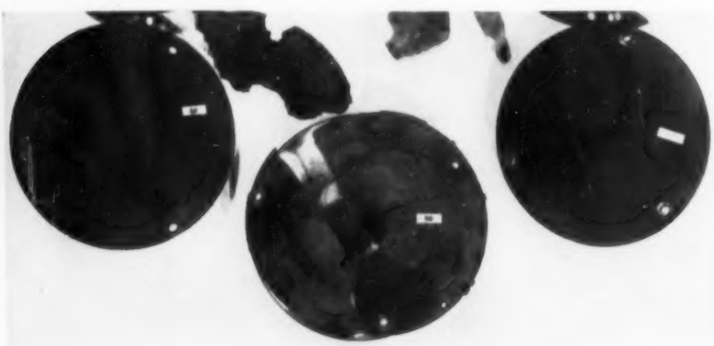
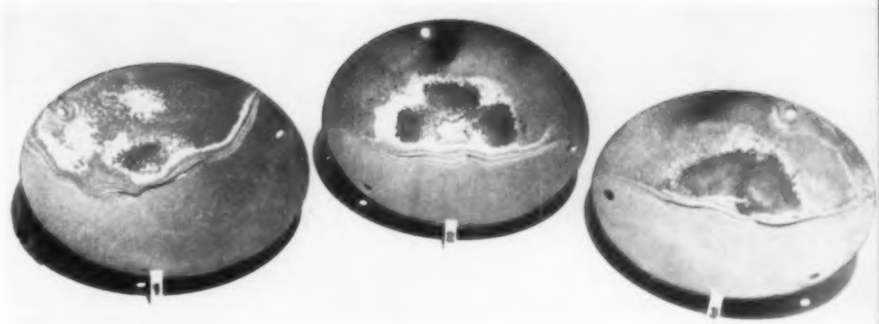


Fig. 6 – Three Plates With Laminated Coatings After Testing. The first and third tests stood up well, while the second (which includes a molybdenum liner) failed. However, the plate did not burn through

Fig. 7 – *Three Plates With Laminated Coatings Sand-Blasted to Reveal the Layers. The second plate withstood two rocket blasts*



lation of the coating is its inherent porosity. Entrapped air effectively aids both the insulating and thermal shock resistant qualities of the multilayer coating. Furthermore, gas in the voids, as a result of volume increase upon heating, has not proven detrimental to the bond strength of the coating. The voids are small and for the greater part are in contact with the atmosphere. We feel that the insulation value of the coating can be improved by proper control and distribution of porosity.

These coatings also have good compressive strength. Where ductile metals (such as copper or 300 series stainless steel) compose the metallic layers, considerable distortion is possible before the coating fails. However, the harder, more brittle, metals crack with little distortion. The coating can be ground and polished to a fine finish, yet it provides an excellent base for lubricants. Because of its porosity, it is a natural for use as a self-lubricating bearing or shaft.

Similar tests are being performed using various multilayer coating combinations. Metals besides molybdenum, and ceramics other than alumina (both being applied to other back-up materials), have been tried. Among other things, we found that all the back-up plates on which zirconia was employed (as a substitute for Al_2O_3) performed poorly regardless of the laminating metal used. In most instances, a complete burnout occurred.

Oddly, however, a fiberglas back-up dome (0.040 in. thick) covered with a molybdenum-alumina coating having total thickness of 0.050 in. survived the test without burn-through. This encouraging result indicates that the coating should find wide application in the aircraft industry for protection of leading edges fabricated from organic materials.

Several other test programs are being conducted on these coatings to determine their limitations under different conditions. So far, results have been gratifying.

A metal-ceramic multilayer coating applied for prolonged operation at 3000° F. withstood extreme erosive and corrosive hot gases under conditions of severe vibration for over 18 min. Two cool-down periods are allowed, if required, during use. In this instance, the coating is tailored to serve a specific service condition – the laminations being much thinner and more numerous than before. We are now attempting

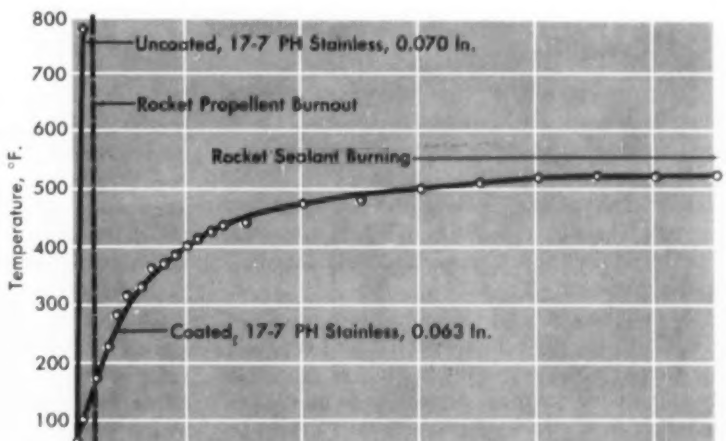


Fig. 8 – *Graph Showing Insulating Properties of Coating*

to vary the coating so that it will last for unrestricted periods at 4500° F.

Applying the Coating

The coating is fairly easy to apply; however, careful preparation of the surface is essential. After thorough cleaning and grit blasting with clean alumina (or a crushed 20 to 40-mesh quartz-type grit), the part is ready for metallic or ceramic spray.

Molybdenum is sprayed on the part from a conventional oxy-acetylene metallizing gun. When applied in this manner, a visible smoke of MoO_3 appears. This oxidation, which occurs at about 1400° F. (considerably below the 4700° F. melting point of molybdenum), permits uncontaminated molybdenum to unite strongly with the base metal. Alumina is sprayed on the molybdenum; and here the bond is strictly mechanical.

Alumina was applied from rod form by feeding a cylindrical extruded alumina rod, 1/8 in. diameter, at 6 in. per min. into the tip of an oxy-acetylene flame. Compressed air at 80 psi. projected the molten particles about 4 in. to the base material where they noticeably flattened and froze.

Powdered alumina was also used. The spray gun used to apply powdered alumina uses a gravity feed from a powder hopper through a metering valve. Powder is drawn at reduced pressure into a siphon chamber, and propelled into the nozzle by a controlled stream of oxy-acetylene. A siphon-jet arrangement at the gun nozzle helps to propel the plastic particles, and a small electrically operated vibrator attached to the gun below the nozzle assures smooth flow.

Possible Variations

The advantages of this multilayer coating are numerous, particularly when variations are taken into consideration. For instance, vaporization and sublimation materials can be added. Tin, zinc, nickel, cobalt, certain halides, silicones, furanes, phenols, epoxies and others, may be introduced by postimpregnation or controlled dual application. The following possible advantages may be obtained:

1. Corrosion protection essential for long shelf life can be obtained. Metals such as zinc and cadmium offer corrosion protection to most base materials in a sacrificial manner; they need not be dense to protect the base material under storage conditions.

2. Life at high temperatures can be extended. Many Btu.'s are needed to vaporize or to sublime the impregnating material.

3. The coating protects at temperatures well above the melting points of all materials used. If the impregnating material should be a silicone, halide, or one of the metallic compounds of higher vaporization point, the coating could be laminated and impregnated so that controlled cooling is obtained.

A highly emissive top coating will reduce the heat caused by atmospheric friction such as encountered on re-entry. Coatings such as chromium oxide and certain carbides could provide such protection.

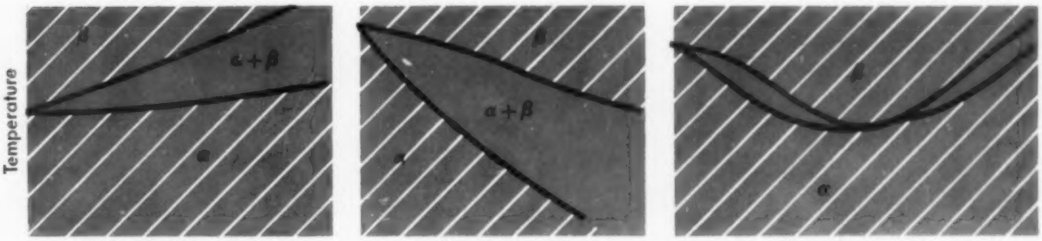
Chromizing, siliconizing, aluminizing and in some instances nitriding of the coating may provide better corrosion resistance. When chromium or silicon are diffused into the surface of molybdenum or ferrous alloys, both elements greatly enhance the metal's resistance to corrosion at all temperatures in an oxidizing or reduc-

(*Continued on p.* 189C)

Table II – Materials for Flame Spraying

Metals	Melting Point	Density Lb. Per Cu.In.
Beryllium*	2340° F.	0.0658
Boron	4200	0.083
Chromium	3430	0.260
Cobalt	2723	0.320
Columbium	4380	0.310
Iridium	4262	0.813
Molybdenum	4760	0.369
Nickel	2651	0.322
Platinum	3224	0.775
Rhodium	3610	0.450
Tantalum	5425	0.600
Tungsten†	6170	0.697
Tin‡	449 B.P. 4100	0.264
Vanadium	3100	0.217
Zirconium	3452	0.234
Ceramics		
Al_2O_3	3720	0.141
BeO*	4660	0.108
Cr_3C_2	3740	0.242
Cr_2O_3	4125	0.188
MgO	5070	0.126
$(3\text{-}Al_2O_3 \cdot 2\ SiO_2)$	3326	0.111
SiC	4082	0.115
TiC	5880	0.176
W_2C	4890	0.625
ZrO_2	4870	0.209
$ZrSiO_4$	4532	0.169

*Vapors exceedingly toxic.
†Must be applied in an alloyed or combined state.
‡Suitable as an impregnating material.



Alpha Stabilizing *Beta Stabilizing* *Neutral*

Fig. 1 – The Three Types of Alpha-Beta Relationships. Of the metallic alloying elements, aluminum is the only alpha stabilizer, while tin and zirconium behave neutrally. Molybdenum, vanadium, manganese, iron and chromium are beta stabilizers. (Fig. 1 and 4 from TML Report No. 78, Battelle Memorial Institute)

Titanium Alloys Today

*By PAUL D. FROST**

Though the glamour is wearing off, titanium is definitely being established as a useful structural material. It is light, strong, and temperature resistant. Through alloy additions, either alpha or beta phase can be stabilized. Heat treatments, much like those used for steels, enhance the mechanical properties, particularly those of the alpha-beta and beta alloys. (N-general, Q-general, J-general; Ti-b)

TITANIUM, which had the dubious distinction of being a "wonder metal" a few years ago, and which survived a major recession last year, appears now to be well established in its proper role as another structural material. Though it may be a few more years before department stores are selling titanium saucepans and before automobiles are equipped with rustproof titanium tailpipes, we will soon be riding from New York to Los Angeles in jet liners which are designed around vital titanium parts. Because of high cost of the metal, the titanium industry will continue to lean heavily on aircraft for its existence. However, with sponge and mill products now as low in price as they have ever been, titanium should become more attractive for ordnance, marine and chemical processing applications.

Compared with older metals, the number of commercial titanium alloys is not large. However, the rapid development of new alloys during the past few years has been due to the extensive research programs by the government and the titanium producers.

Like other structural metals, titanium is sold as "commercially pure" in several degrees of purity, as well as in alloy form. Oxygen, nitrogen and hydrogen are impurities in all titanium products. The first two are desirable when controlled within specified limits; this is accomplished by blending different grades of sponge. Hydrogen is always undesirable.

Oxygen and nitrogen are alpha stabilizers. As shown in Fig. 1, both elements raise the temperature at which alpha titanium transforms to beta. They also raise the hardness of alpha titanium, and as hardness increases, strength increases.

*Chief, Light Metals Div., Battelle Memorial Institute, Columbus, Ohio. Part II on properties and applications of titanium alloys will appear next month.

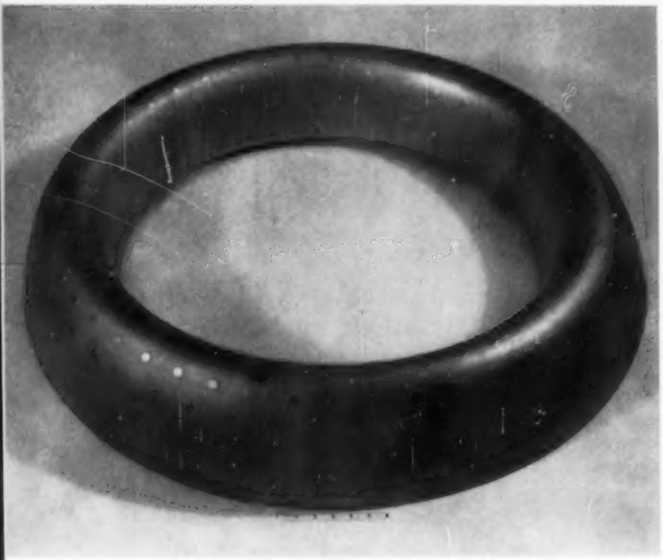


Fig. 2 – Inner Portion of Convair Jetliner Nose Cowl. This part is made from commercially pure titanium. (Fig. 2 and 3 courtesy Convair, San Diego Div.)

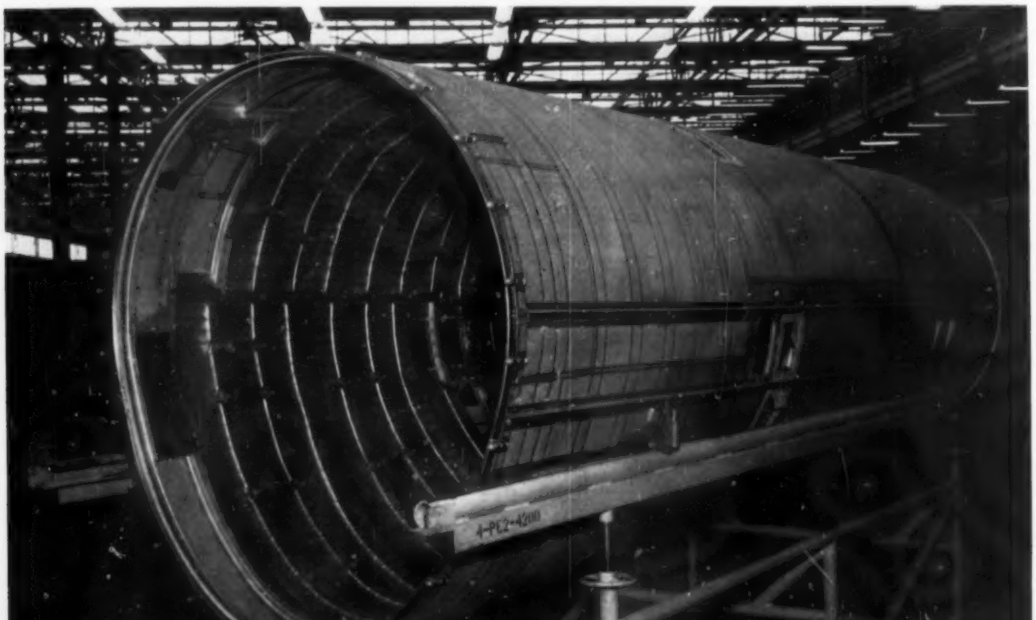
Fig. 3 – Engine Shroud for Convair F-106 Fighter. The outer skin is unalloyed titanium sheet which has been "rigidized"

Simultaneously, however, ductility and toughness decrease. With increased strength and decreased ductility, some decrease in formability is inevitable. Nevertheless, even the strongest unalloyed titanium has good formability and is used for many aircraft parts carrying relatively low stresses.

An example of this type of application is the inner portion of the Convair Jetliner nose cowl (manufactured by Rohr Aircraft) shown in Fig. 2. In making this cowl, three segments of commercially pure titanium are welded, then covered by a riveted titanium skin. The raised pads, which act as separators under the outer skin to allow for hot air flow, are produced by chemical etching of the titanium between the pads. An engine shroud for the Convair F-106 fighter (Fig. 3) uses commercially pure titanium as "rigidized" sheet for the outer skin. The shroud weighs some 200 lb.; substituting titanium for steel is estimated to have saved about 130 lb.

Alloying Behavior

A large number of metallic elements alloy readily with titanium. Aluminum is the only metal used in commercial alloys which dissolves preferentially in the alpha phase. It behaves like oxygen and nitrogen in raising the beta transformation temperature. Since stabilization of the



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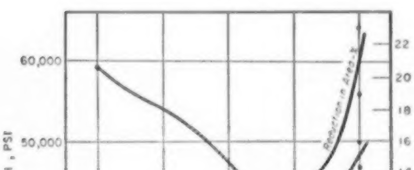
Ni-Resist* ductile irons are a new family of versatile high-alloy cast irons developed by Inco. Containing 18 to 36% Nickel, they provide the same high order of corrosion and heat resistance given by Ni-Resist flake graphite iron...plus high levels of strength and ductility.

There are several types of Ni-Resist ductile iron. Each one combines a useful array of engineering properties.

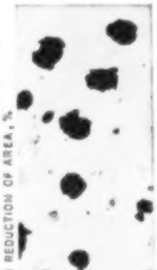
Strength Ni-Resist ductile irons provide tensile strengths of 55,000 to 80,000 psi, yield strengths of 30,000 to 44,000 psi. See graph of properties below.

Toughness Ni-Resist ductile irons give elongations of 4 to 40%, together with good impact resistance. The photomicrograph below shows why – spheroidal graphite particles allow formation of an austenitic matrix. This nickel alloy matrix develops full ductility and strength . . . keeps these properties at low temperatures.

Corrosion resistance Ni-Resist ductile irons safely handle hundreds of corrosives. Under most conditions – with acids, alkalies and salts – their performance is far superior to both cast iron and steel, helping you reduce maintenance costs.



High temperature tensile properties of Type D-2 Ni-Resist ductile iron.



Ni-Resist ductile microstructure X 100. Spheroidal graphite particles allow the metal to develop the full strength and toughness of the high alloy austenitic matrix.

High temperature properties Ni-Resist ductile irons form a tightly adhering scale at elevated temperatures, greatly reducing further oxidation. They resist heat effects up to 1400°F and higher, have excellent thermal shock resistance. From 1100° to 1300°F, Type D-2 has stress rupture properties equal to those of cast HF stainless steel.

Wear resistance Ni-Resist ductile irons have a work hardening austenitic matrix. Graphite particles provide dry lubrication. Both properties work together to resist wear and galling over a wide temperature range.

Erosion resistance Ni-Resist ductile irons work well in wet steam, brine or salt slurries, and high velocity liquids. Their high strength and resistance to cavitation-erosion mean long service life for pump parts.

Controlled expansion Ni-Resist ductile irons have thermal expansivities from about 2.5 up to 10.4 millionths per degree F. You can match them with steels, cast irons, Nickel, Monel* alloy...with aluminum, copper, bronze and stainless steel.

Non-Magnetic properties Ni-Resist ductile irons, Types D-2 and D-2C, are non-magnetic and therefore useful where excessive heat and power losses must be avoided.

Machinability Ni-Resist ductile irons machine as well as common pressure-type gray iron, thanks to the presence of graphite in their structure.

Fluidity in casting Ni-Resist ductile irons have good flowing qualities and permit the making of intricate designs.

These are only the highlights. You can get *all* the facts on this versatile new family of metals by asking us for "Engineering Properties of Ni-Resist Ductile Irons." This 28-page booklet details engineering properties and commercial applications with numerous photos, tables, and graphs . . . gives you the information you need to decide how Ni-Resist ductile irons can help you. You'll also get "Buyers' Guide for Ni-Resist and Ni-Resist Ductile Iron Castings", listing foundries authorized to produce them.

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NI-RESIST DUCTILE IRONS
NICKEL ALLOYED IRONS PERFORM BETTER LONGER

Commercial and Semicommercial Titanium Mill Products

Nominal Composition Weight %	Producer's Designations* Crucible	Mallory-Sharon	Republic	TMCA	Specifications A.M.S.	A.S.T.M.	Military	Mill Forms †	Condition ‡	Form	Mechanical Properties§ Tensile (1000 psi.)	Yield (1000 psi.)	Elong.
Unalloyed Titanium													
High purity (99.9%)	(Iodide produces crystal bar and comparable material)								Annealed	—	34(16)	20(—)	54(52)
Unalloyed (99.2%)	A-40	MST-40	RS-40	Ti-35 A, 45 A, 55 A	4902	B 265-58 T-Gr 2	MIL-T-9047 B-1	B, S, T, W	Annealed	—	59(28)	40(13)	28(—)
Unalloyed (99.0%)	A-55	MST-55	RS-55	Ti-65 A	4900 A	B 265-58 T-Gr 3	MIL-T-9047 B-1	B, S, T, W	Annealed	—	79(33)	63(19)	27(33)
Unalloyed (99.0%)	A-70	MST-70	RS-70	Ti-75 A Ti-100 A	4901 B 4921	B 265-58 T-Gr 4	MIL-T-9047 B-1	B, S, T, W	Annealed	—	95(43)	80(27)	25(28)
Alpha Titanium Alloys													
6 Al, 4 Zr, 1 V	—	—	—	Ti-6Al-4Zr-1V	—	—	—	S	Annealed [1325° F. (4 hr.) AC]	Sheet	143(90)	138(76)	17(20)
5 Al, 2.5 Sn	A-110 AT	MST-5Al-2.5Sn	RS-110C	Ti-5Al-2.5Sn	4926	B 265-58 T-Gr 6	MIL-T-9047 B-2 MIL-T-9046 B-3	B, S, T, W	Annealed	—	125(82)	120(65)	18(17)
8 Al, 1 Mo, 1 V	—	—	—	Ti-8Al-1Mo-1V	—	—	—	B, S	HT [1800° F. (5 min.) AC] [1100° F. (8 hr.) AC]	Sheet	147(112)	135(88)	16(16)
8 Al, 2 Cb, 1 Ta	—	MST-821	—	—	—	—	—	B, S, W	Annealed [1650° F. (1 hr.) AC]	Bar	126(100)	120(81)	17(25)
8 Al, 8 Zr, 1 (Cb + Ta)	—	MST-881	—	—	—	—	—	B	Vacuum annealed [1600° F. (8 hr.) FC to 600° F.]	Bar	135(110)	125(98)	16(17)
Alpha-Beta Titanium Alloys													
3 Al, 2.5 V	—	MST-3Al-2.5V	—	—	—	—	—	S, T	Annealed	Strip	100(—)	85(—)	15(—)
5 Cr, 3 Al	—	MST-3Al-5Cr	—	—	4927	—	MIL-T-9047 B-3	B, S	Annealed	Bar	155(114)	145(88)	14(15)
8 Mn	C-110 M	MST-8Mn	RS-110 A	—	4908 A	B 265-58 T-Gr 7	MIL-T-9046 B-1	S	Annealed	Sheet	138(103)	125(83)	15(13)
2 Fe, 2 Cr, 2 Mo	—	—	—	Ti-140 A	4923	—	MIL-T-9047 B-4 MIL-T-9046 B-4	B, S, T	Annealed	Bar	137(95)	125(65)	18(19)
									HT [1480° F. (1 hr.) WQ; 900° F. (24 hr.) AC]	Bar	179(136)	171(112)	13(16)
4 Al, 4 Mn	C-130 AM	MST-4Al-4Mn	RS-130	—	4925 A	—	MIL-T-9047 B-6	B, S, W	Annealed	Bar	148(110)	133(90)	16(17)
									HT [1450° F. (2 hr.) WQ; 900° F. (24 hr.) AC]	Bar	162(125)	140(100)	9(11)
4 Al, 3 Mo, 1 V	C-115 AMoV	MST-4Al-3Mo-1V	RS-115	Ti-4Al-3Mo-1V	—	—	—	S	HT [1625° F. (2½ min.) WQ]	Sheet	140(—)	95(—)	15(—)
									HT [1625° F. (2½ min.) WQ; 925° F. (12 hr.) AC]	Sheet	195(152)	167(113)	6(7)
4 Al, 4 Mo, 4 V	—	—	—	Ti-4Al-4Mo-4V	—	—	—	B	HT [1550° F. (1 hr.) WQ; 1000° F. (6 hr.) AC]	Bar	170(—)	150(—)	6(—)
5 Al, 2.75 Cr, 1.25 Fe	—	—	RS-140	—	—	—	—	B, S	Annealed	Sheet	155(118)	135(102)	14(12)
									HT [1475° F. (6 min.) WQ; 900° F. (5 hr.) AC]	Sheet	195(140)	165(116)	6(8)
5 Al, 1.5 Fe, 1.4 Cr, 1.2 Mo	—	—	—	Ti-155 A	4929	—	MIL-T-9047 B-7	B, S	Annealed	Bar	154(115)	145(100)	16(16)
									HT [1650° F. (1 hr.) WQ; 1000° F. (24 hr.) AC]	Bar	195(150)	184(125)	9(14)
6 Al, 4 V	C-120 AV	MST-6Al-4V	RS-120 A	Ti-6Al-4V	4911 4928	B 265-58 T-Gr 5	MIL-T-9047 B-5 MIL-T-9046 B-2	B, S, T, W	Annealed	Sheet	135(105)	120(95)	11(11)
									HT [1700° F. (20 min.) WQ; 975° F. (8 hr.) AC]	Sheet	170(130)	150(105)	7(7)
7 Al, 4 Mo	C-135 AMo	MST-7Al-4Mo	RS-135	Ti-7Al-4Mo	—	—	—	B, T	Annealed	Bar	160(125)	150(17)	15(17)
									HT [1650° F. (20 min.) WQ; 900° F. (16 hr.) AC]	Bar	190(155)	175(120)	12(15)
2.5 Al, 16 V	C-105 VA	MST-2.5Al-16V	—	—	—	—	—	B, S, W	HT [1380° F. (20 min.) WQ]	Sheet	105(—)	45(—)	16(—)
									HT [1380° F. (20 min.) WQ; 960° F. (4 hr.) AC]	Sheet	180(140)	165(130)	6(8)
Beta Titanium Alloys													
13 V, 11 Cr, 3 Al	B-120 VCA	—	RS-120 B	Ti-13V-11Cr-3A	—	—	—	B, S, W	HT [1400° F. (30 min.) AC]	Sheet	135(—)	130(—)	16(—)
									HT [1400° F. (30 min.) AC; 900° F. (16 hr.) AC]	Sheet	180(175)	170(145)	6(3)

*Producers of Mill Products: Crucible Steel Co. of America, Titanium Div., Midland, Pa.; Mallory-Sharon Metals, Inc., Niles, Ohio; Republic Steel Corp., Massillon, Ohio; Titanium Metals Corp. of America, New York, N.Y.

†B—bars and billets; S—rolled flat products (sheet, strip and plate); W—wire; T—tubes and extrusions.

‡HT—heat treatment; AC—air cooled; WQ—water quenched; FC—furnace cooled.

§Figures in parentheses and italic are properties at 600° F.; others are room-temperature values. All figures indicate comparative strength levels.

Compiled from data to be released by Defense Metals Information Center, Battelle Memorial Institute, Columbus, Ohio

alpha phase promotes stability at higher service temperatures, aluminum is a vital element in most titanium alloys.

However, most alloying elements used in commercial titanium alloys (iron, manganese, chromium, molybdenum and vanadium, for example) dissolve preferentially in the beta phase. Thus, as Fig. 1 shows, they stabilize it at temperatures below which unalloyed beta titanium is stable. Recently, columbium and tantalum have been added to the list; these are used in Mallory-Sharon's new 8Al-2Cb-1Ta alloy. In this alloy, the amount of columbium and tantalum is not sufficient to retain the beta phase at room temperature. Principally, they strengthen the alloy and help prevent embrittlement caused by formation of titanium-aluminum compounds.

Beta-stabilizing elements can be classified into those which form intermetallic compounds with titanium (eutectoid formers) and those which form stable solid solutions with the beta phase (beta isomorphous elements). Manganese, chromium, and iron are sluggish eutectoid formers; nickel, copper and silicon diffuse more rapidly in beta titanium, and are known as active eutectoid-forming elements. Hydrogen is the only nonmetallic beta-stabilizing element, but is considered an impurity, not an alloying element.

Tin and zirconium, having no strong preference for alpha or beta, dissolve in both. These two elements are used in several titanium alloys to supplement the more effective alpha or beta-stabilizing elements.

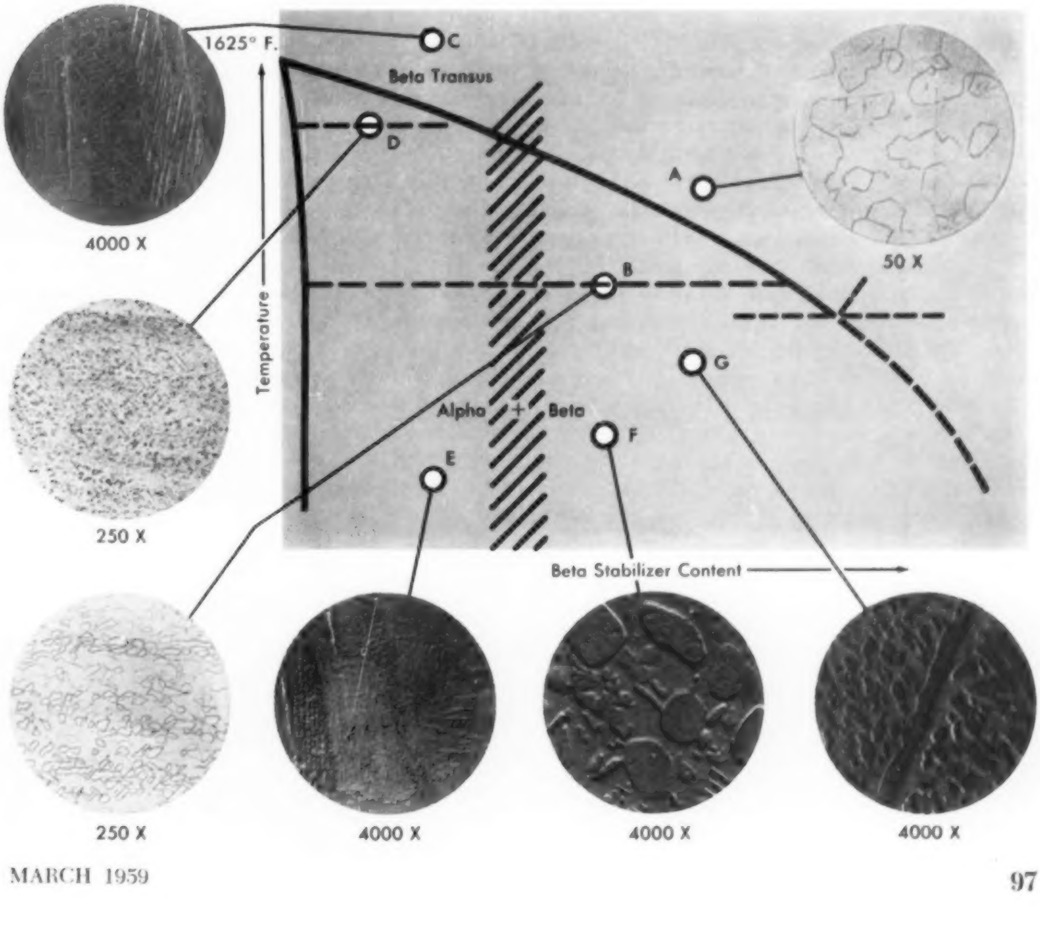
Beta stabilizers are necessary for at least two major reasons:

1. The beta phase can develop greater strength through solid-solution effects than can the alpha phase.

2. Commercial titanium alloys containing beta-stabilizing elements can be heat treated.

Titanium, like iron, has a phase transformation (1625° F); this makes its alloys heat treatable.

*Fig. 4 – Constitution, Heat Treatment and Microstructure of **Titanium Alloys**. Treatments needed to produce the illustrated microstructures are discussed in the text*



The relationships between this transformation, the beta-stabilizing elements and the response to heat treatment is explained most easily by a schematic phase diagram (Fig. 4).

The simplest type of microstructure is the retained beta phase (A) which is developed in alloys containing over a minimum amount of beta-stabilizing elements. This minimum range is indicated by the shaded area of the diagram, and represents about 3.5% Fe, 6.5% Mn or Cr, 10% Mo, or 15% V. In such compositions, or their equivalent, retained beta is produced by cooling rapidly from the beta field. Transformation on cooling through the alpha-beta region is thus suppressed, and the resulting microstructure is thermally unstable* at room temperature.

It is this metastability which permits heat treatment of the alpha-beta alloys. Hardening occurs when some of the beta is transformed into fine particles of alpha or some intermediate phase. This is denoted by "G" (in Fig. 4). After quenching from the beta field, the alloy was reheated in the alpha-beta field. The long strip shown in the electron micrograph is a portion of alpha phase existing in what was formerly a beta grain boundary; finer alpha particles have precipitated within the grains.

The mechanism of age hardening in alpha-beta titanium alloys may be summarized by these equations:

$$\beta_o \rightarrow \beta_r + \omega \rightarrow \beta_r + \omega + \alpha \rightarrow \beta_u + \alpha$$

$$\beta_u + \alpha \rightarrow \alpha + Ti_xM_y \text{ (in eutectoid systems)}$$

β_o, β_r, and β_u are beta of original, enriched and ultimate alloy contents, respectively. Omega (ω) is a transition phase; it is responsible for the brittleness associated with the early stages of aging. As omega and alpha are formed, they reject the beta-stabilizing elements, and the remaining beta becomes richer in alloy content. The final product of aging is alpha plus highly enriched beta, or, if an element which forms intermetallic compounds is present, alpha plus compound. Of course, in practical heat treating, aging is terminated while the alpha precipitate is relatively fine. This insures high strength, and brittle compounds have no chance to form.

When the alloy indicated by "B" is solution treated and quenched from inside the alpha-beta field (Fig. 4) it consists of retained beta with islands of alpha. If the quenched alloy is then aged at temperature "F", the beta decomposes partially to produce a fine dispersion of alpha. The resulting aged structure (F) then consists of a beta matrix, large particles of primary alpha (which existed at the solution temperature), and small particles of precipitated alpha.

Lean Alpha-Beta Alloys – The preceding discussion applies only to alloys fairly rich in beta-stabilizing elements, such as Ti-2Fe-2Cr-2Mo or Ti-4Al-4Mn. However, lean alpha-beta alloys of the Ti-6Al-4V type harden in a different manner. Beta phase with alloy content less than that indicated by the crosshatched area in Fig. 4 is not retained on quenching; instead it transforms to the hexagonal (alpha prime or titanium martensite) phase. For instance, the structure of the alloy shown at "C", quenched from the beta field, consists of a supersaturated alpha phase formed by a martensite-type shear reaction. Fine martensite needles can be seen in the electron micrograph. Unsaturated alpha needles may also form if the cooling rate is slightly lower.

The alpha-prime microstucture is not an equilibrium structure, and aging will produce mechanical property changes. The structure at "E" illustrates the effects of aging. Simplified, the reaction is believed to be as follows:

$$\beta_o \rightarrow \alpha'$$

$$\alpha' \rightarrow \alpha + \beta$$

Actually the reaction may be more complex. Here, α' is the transition phase, which is supersaturated with beta-stabilizing elements, while α and β are the final products. The hardening caused by this reaction is slight compared to that accompanying the omega hardening reaction.

If the lean alpha-beta alloys are solution treated just below the beta transus (Fig. 4), as at temperature "D", the beta-phase composition falls to the left of the crosshatched area, and beta is not retained on quenching. When solution treated at lower temperatures, the beta composition may be rich enough to cause some retention of beta. However, the amount of retained beta is generally small; hence, the extent to which such alloys can be strengthened by heat treatment is limited.

This review of alloying behavior and heat treatment should promote a better understanding of commercial alloys. Property data are provided in the Data Sheet (p. 96-B).

Part II of this article next month will discuss properties and applications of commercial and semicommercial alloys.

*The stability of the retained beta increases with increasing amounts of beta stabilizer. For example, the new commercial Ti-13V-11Cr-3Al alloy contains enough vanadium and chromium to permit air cooling from the beta field without decomposition. However, even this alloy is metastable, and will partially transform to alpha if aged for a number of hours at 800 or 900° F.

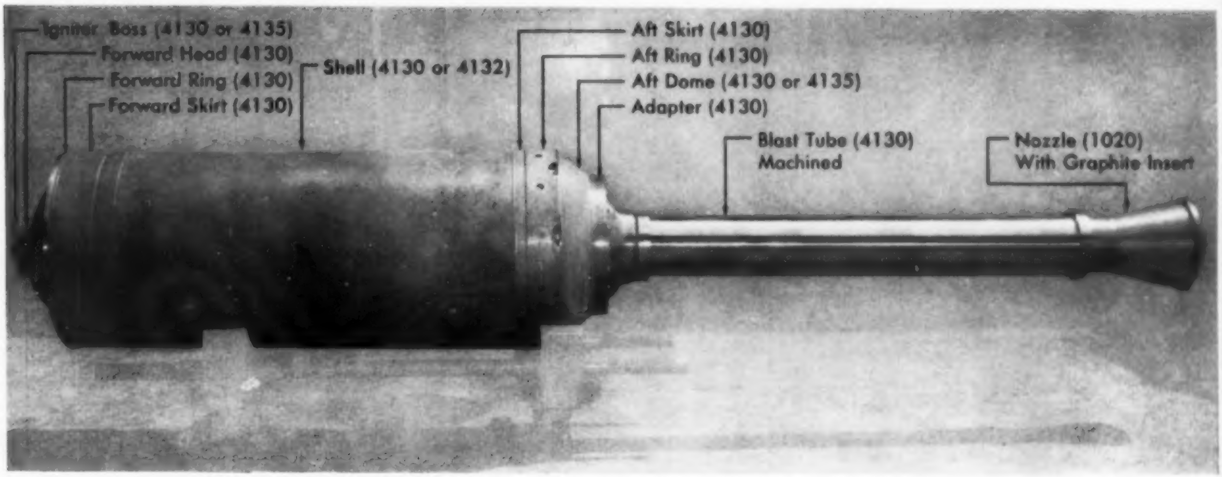


Fig. 1 – Rocket Engine Case Assembled With Adapter, Blast Tube and Nozzle

Welding and Heat Treating Rocket Cases

*By C. N. SCOTT**

Rocket engine cases are fabricated from precise weldments of alloy steels which are heat treated to give high strength. Cases are quenched from austenitizing temperature into salt at 350° F. to minimize distortion. (J22, J2j, K1, T2p, AY)

USES for solid propellant rocket engines have required larger sizes than anticipated a few years ago. As a result, equipment to fabricate engine hardware has been limited, particularly for heat treating. To meet these needs, we have just completed and put into operation a facility which increases by 50% an already large rocket production plant.

Several processes have been used to manufacture rocket cases, but the major one has been the rolled and welded process. We have fabricated units ranging from a diameter of 6 in., 50 in. long, to a diameter of 72 in., 14 ft. long. To illustrate our new facilities, a rocket motor case will be followed through the shop during fabrication. The rocket considered is a sustainer unit – a difficult motor to fabricate because of extremely close tolerances. It is shown in Fig. 1, as a complete unit, assembled with adapter, blast tube and nozzle. Dimensional control is of utmost importance, and selective fitting of parts and assemblies is required to insure that the finished motor will be within tolerances.

Due to rigid heat treat specifications, alloy steels are used so that physical properties required after heat treating can be met. The tube section, which is about 28 in. diameter and 55 in. long, is fabricated from 4130 or 4132 steel. Other parts are made of 4130, 4132 and 4135 grades, as shown in Fig. 1. The nozzle section is machined from a 1020 forging or casting and uses a throat insert made from graphite for heat resistance.

*Manager, Rocket Engineering Dept., Goodyear Aircraft Corp., Akron, Ohio.

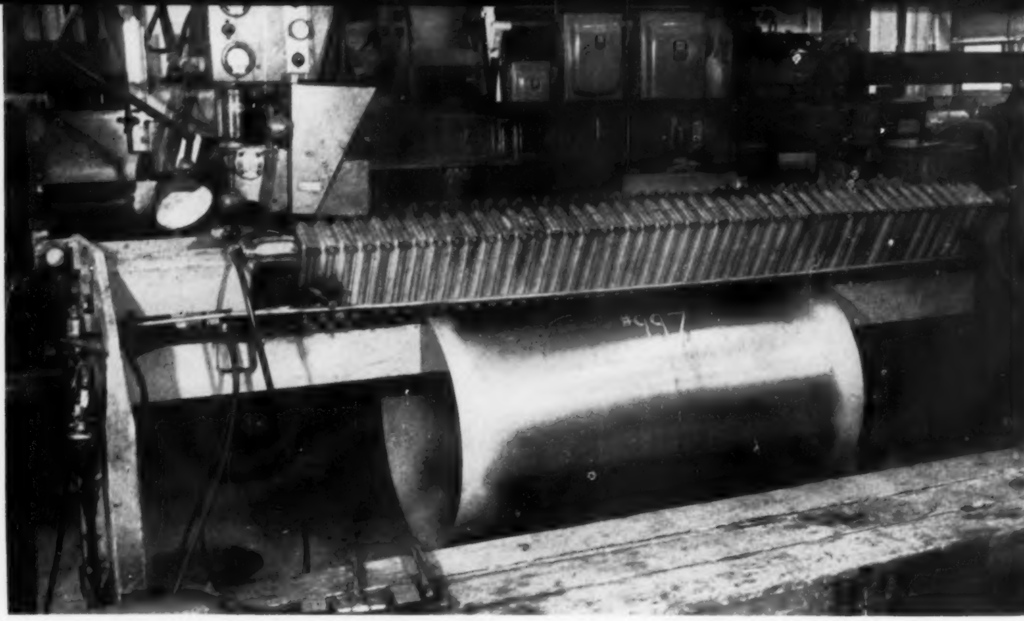
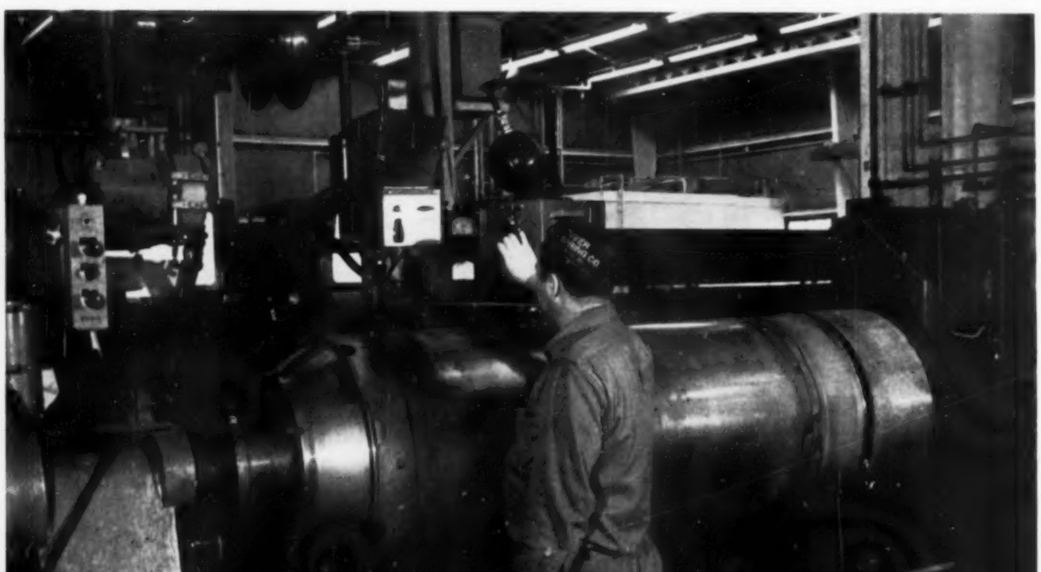


Fig. 2 – After Rolling Alloy Steel Sheet to Give the Proper Diameter Tube, the Piece Is Placed in This Special Fixture for Welding by the Submerged Arc Process

Fig. 3 – This Special Fixture Is Used in Welding Accessories and Fittings to the Tube to Give the Engine Case Assembly. All areas to be welded are preheated to 200° F. Entire assembly is stress-relieved at 1100° F. for 1 hr.



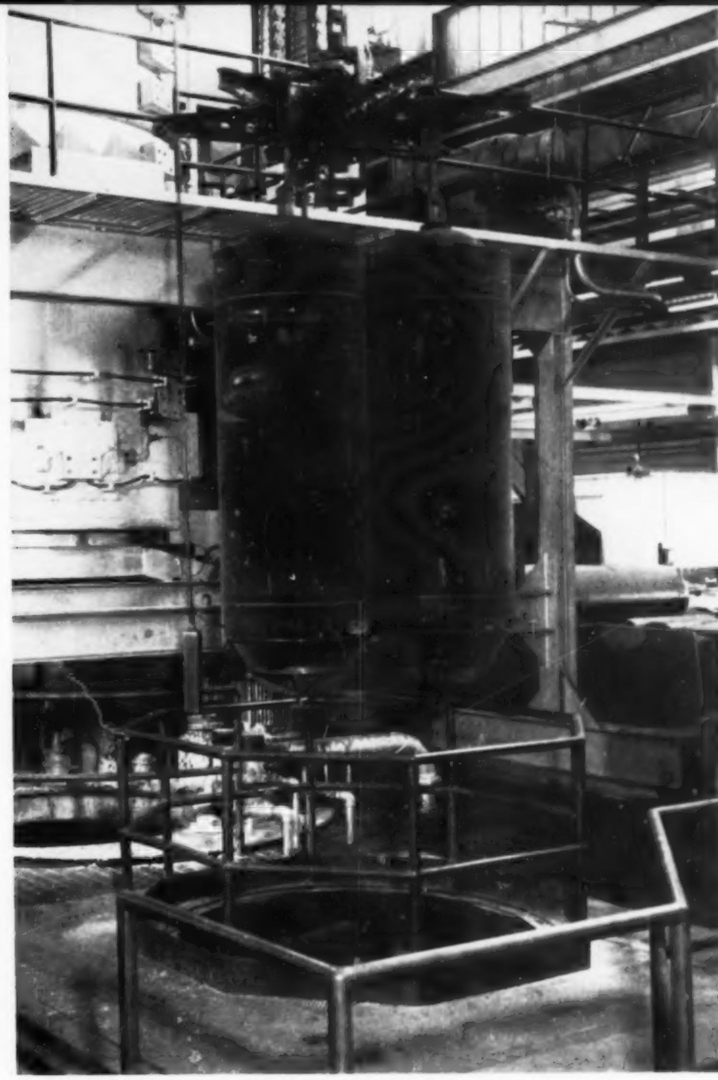


Fig. 4 – Rocket Engine Cases Are Heat Treated in Clusters of Three. This batch, held by a special fixture, is ready for loading into the heat treating furnace

Start of Fabrication Process

Steel sheet is cut to length (maintaining very close tolerances), squared and rolled to the required diameter. After rolling, the edges of the sheet are carefully cleaned, and the piece is placed in the special fixture shown in Fig. 2 for welding longitudinally to form a tube. Welding is done automatically with the submerged arc process. The weld is checked with X-ray and inspected with Magnaflux. The tube is then examined for concentricity and bow.

The aft dome assembly, consisting of the aft skirt assembly and a machined dome, is fitted to the tube. The forward head assembly, consisting of a centrally located igniter boss, forward skirt, and formed head, is also fitted to the tube. The complete assembly is placed in the special fixture shown in Fig. 3 and welded, using the submerged arc process as before.

Careful control of preheat and postheat is required for good welds. Gas torches are mounted on the fixture in Fig. 3 and all weld areas are heated to about 200° F. prior to welding. After welding, this temperature is maintained until the completed assembly goes into the furnace for stress-relief. This requires heating at 1100° F. for about 1 hr. Furnace is cooled to 900° F., then the assembly is removed and allowed to air cool. After stress-relieving, all welds are inspected with X-ray and Magnaflux.

Heat Treating Minimizes Distortion

Rocket case assemblies are now ready for heat treating. They are processed in clusters of three. Figure 4 shows a lot mounted on a special fixture, ready for loading. The furnace, which is heated electrically, has a working section 68 in. in diameter by 21 ft. long. It is a bottom-load, bottom-drop furnace of the vertical gantry type.

Cases are heated in an inert atmosphere produced by a generator constructed by Gas Atmospheres, Inc., which gives high-purity nitrogen. In addition to nitrogen the atmosphere contains a small amount of hydrogen and carbon monoxide (up to 3%), which makes it slightly reducing. The furnace has five-zone control and is certified for operation up to 1900° F. with control within ±20° F. It spans a pit (18 by 53 by 25 ft. deep) which contains two tempering furnaces, a hot water wash tank, a slat bath quench tank, and a loading station. The salt quench is of the nitrate-nitrite type supplied by E. F. Houghton Co., and can be operated in the range 325 to 1000° F. The quench can be controlled within ±3° F.

Draw furnaces can be operated in the range of 400 to 1400° F., controlled within ±15° F. Pit furnaces can be altered to supply a quench of hot air, salt, oil or water, if needed. The furnace moves along the pit on rails to give any sequence of operations required. The furnace line was designed and erected by Lindberg Industrial Corp.

Rocket cases are loaded in the furnace where they are austenitized at 1600° F. Time required to reach temperature is ½ to ¾ hr., and parts are held at temperature for 1½ hr.

The furnace is then positioned over the salt quench tank, and the load is dropped rapidly into the tank for quenching at 350° F. Parts remain in quench for 20 min. Figure 5 shows cases at 1600° F. positioned over the quench tank.

After quenching, the load is cleaned in a wash tank to remove salt. Rocket cases are then placed in the tempering furnace at 820° F. for 3 hr. Following this, cases are again checked for concentricity ("out of round"), which must be held within 0.150 in. T.I.R. (total indicator reading). They are then lightly sand-blasted and oiled. Yield strength of heat treated cases is in the range of 145,000 to 170,000 psi.

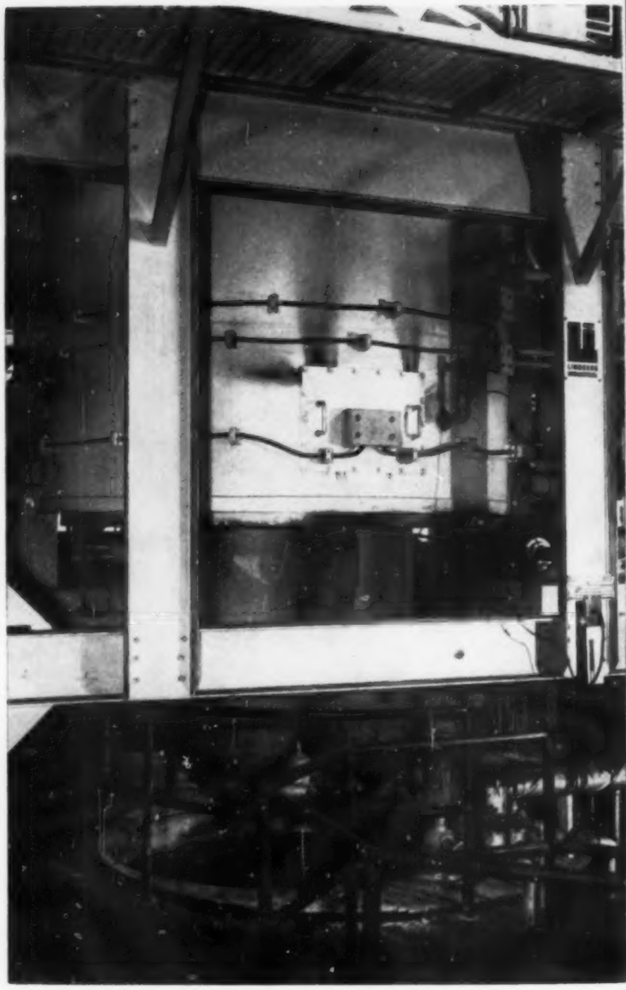


Fig. 5 – Cases at 1600° F. Are Dropped Rapidly Into Salt Quench Tank Maintained at 350° F. After quenching, the load is washed to remove salt, then placed in draw furnace at 820° F. for 3 hr.

Final Machining of Hardened Material

After heat treating, the units are ready for final machining. Tools must be kept ground and in good condition because surfaces to be machined are hard (Rockwell C-36 to 40) and tolerances are close. In the unit we have described, 50 drilled and tapped holes are required. To do this job, and maintain extreme accuracy, we designed a special drilling machine. It automatically indexes for each of the 97 sequences.

After machining, rocket cases are hydrostatically tested and then inspected. Cleanliness of the units is very important; all machined parts and the complete unit are oiled to prevent rusting. Each unit is packed in a special crate and shipped to the propellant loading facility. Here it is again inspected, following which it is degreased, loaded and painted. After attaching igniter, blast tube, and nozzle, the unit is ready for assembly in the missile.

We have manufactured rocket cases since 1948 – several thousand have been produced. This has included engine cases for the T-29, T-50, Grebe, Nike-Ajax, Nike-Hercules, TE-64 and others. We have worked with many materials – steel, aluminum, magnesium and fiberglas-reinforced plastics.

Hot Work Toolsteel for Aircraft

*By P. E. RUFF**

Used for many years in special dies, the 5% chromium toolsteels (H-11) are being accepted as a structural material in supersonic aircraft and missiles. Heat treatable to 280,000 to 300,000 psi. tensile strength, the steel resists softening up to 925° F. Impact and fatigue strengths are also adequate. (T24, 17-57, Q-general; TS, *Cr*)

WEIGHT is the chief problem facing designers of supersonic aircraft and missiles. Consequently, engineers continually search for higher strength-to-density materials. Along with this requirement, the materials engineer is faced with an associated problem of heat from both power plant and air friction. The need today is for materials with higher strength-to-density ratios which retain strength at elevated temperatures.

Suitable Alloys

Steel, heat treated to 280,000 to 300,000 psi., offers one of the highest strength-to-weight ratios of any material commercially available. For the past several years, low-alloy steels such as 4340 have been heat treated to higher strengths simply by lowering the tempering temperature. However, at these strength levels, tempering temperatures (400 to 500° F.) are lower than moderately high service temperatures.

Toolsteels other than H-11 which might be suitable also have drawbacks. Higher carbon grades lack adequate transverse ductility, massive carbide segregation is a problem, and tendency for decarburization becomes greater. Higher

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carbon also lowers the M_s temperature (as does nickel), and increases the tendency for retained austenite. Highly alloyed steels containing large amounts of the strong carbide-forming elements such as tungsten and vanadium are also undesirable due to segregation.

For the Navy's A3J-1 Vigilante (Fig. 1) built by North American Aviation, Inc., Columbus,

Fig. 1 – North American Aviation's A3J-1 Vigilante. Large amounts of H-11 are used in this jet plane.

Table I – Typical Properties of H-11 Steel Sheet

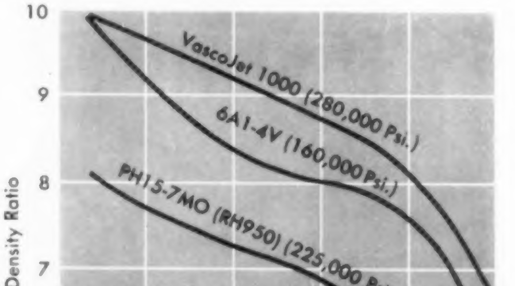
PROPERTY	LONG.	TRANS.
Ultimate tensile strength	277,500 psi.	283,300 psi.
Tensile yield strength	228,500	229,000
Elongation	4.7%	4.5%
Modulus of elasticity	29.0×10^6	29.4×10^5
Compression yield strength	273,700	264,500
Shear strength	177,600	182,600
Bearing ultimate strength	547,300	529,100
Bearing yield strength	387,600	391,900

Table II – Minimum Design Properties

PROPERTY	ALLOWABLE
Ultimate tensile stress	280,000 psi.
Tensile yield stress	230,000★
Compressive yield stress	260,000
Ultimate shear stress	168,000
Ultimate bearing stress	468,000
Bearing yield stress	368,000
Modulus of elasticity	
in tension	29×10^6
in compression	29×10^6
Modulus of rigidity	11×10^6
Weight	0.281 lb. per cu.in.
Elongation†	10%

★220,000 for sheet and plate.
†4% for sheet and plate.

Fig. 2 – Strength-to-Density Ratios for Some Aircraft Structural Materials. VascoJet 1000 is Vanadium Alloy's proprietary version of H-11.



Ohio, 5% Cr hot work toolsteel (or H-11)* has proved an effective heat resistant material with a high strength-to-weight ratio (Fig. 2). Major structural fittings for the Vigilante are made from H-11. In addition, large quantities of this steel in sheets and extrusions are used for fuselage frames and longerons.

For a material to be useful, it must be available. These H-11 steels are procurable in quantity, and almost any form can be purchased. Sheets, plate, strip, bars, billets, forgings and extrusions are among the forms produced today.

H-11 can be heat treated to 280,000 to 300,000 psi. and it resists softening at elevated temperatures. It also has other advantages. It is air hardening, an attribute that lessens warping and distortion during heat treatment. Because it tempers around 1000°F., stress-relief can be done at a fairly high temperature, and high service temperatures are permissible.

for missiles) under multi-axial stresses. To eliminate this discrepancy, some new testing techniques have recently been devised. They employ very high stress concentrations, and successfully predict crack propagation resistance of high-strength sheet materials.

In the design of large, complex structural parts for aircraft, it is practically impossible to avoid large transverse stresses. Therefore, the material must have enough transverse ductility to carry the load. Specifications now require minimum reduction-in-area values in the short transverse direction (established at 6% minimum for 280,000 to 300,000 psi.). This requirement (especially in large billets) still remains a major problem for the steel supplier. Table V shows some typical values.

The H-11 grade retains its strength very well up to its tempering temperature, as Fig. 3 shows. Tests, illustrated by stress-strain curves in Fig. 4,

Table III – Typical Forging and Extrusion Properties

	Direction	Yield Strength	Tensile Strength	Elongation	Reduction in Area
Forging	Longitudinal	234,700 psi.	285,000 psi.	10.2%	38.7%
	Transverse	231,500	285,700	11.1	37.2
Extrusion	Longitudinal	—	279,000	—	45.5
	Transverse	—	284,200	—	36.4

Static Properties

Mechanical properties of H-11 alloy steel sheet (0.063 in. thick) are summarized in Tables I and II. Tempering in the 975 to 1000° F. range gives tensile strength of 280,000 to 300,000 psi. with adequate ductility. (As sheet thickness increases, ductility improves.) Furthermore, many forgings and extrusions exhibit excellent ductility in this strength range, as Table III shows. Reduction-in-area values, both transverse and longitudinal, ranged from 31.3 to 45.8% for all of the tests that were made.

Notch Sensitivity

Regarding notch sensitivity, H-11 has a high notched-to-unnotched tensile strength ratio according to the conventional notched-bar tensile test, as Table IV shows. However, the tests do not always correlate well with the actual behavior of sheet metal structures (such as pressure vessels

*Strictly speaking, a modified H-11 is used; carbon is raised 0.05% for better hardenability and silicon is lowered 0.10% to improve cleanliness.

Fig. 3 – Tensile Strengths of H-11 at Various Temperatures. The analysis range is also included

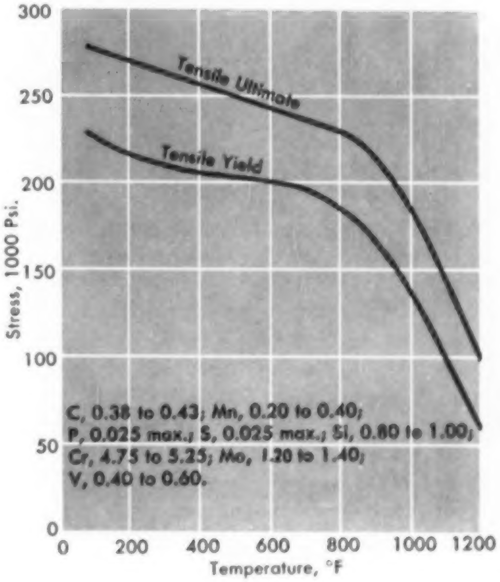


Table IV – Comparison of H-11 Notched Tensile Strength With 4340*

Alloy	Standard				Notched Tensile Strength	Notched-Unnotched Ratio
	Yield Strength	Ultimate Strength	Elongation	Reduction in Area		
H-11	235,700 psi.	283,000 psi.	13.1%	44.2%	383,900 psi.	1.4
4340	228,800	273,600	11.7	42.0	337,000	1.2

*Specimens machined from ⅝-in. diameter bar. All values average of six specimens.

Table V – Short Transverse Tensile Properties of H-11, Midradius Location

Size of Billet	Location in Ingot	Yield Strength	Ultimate Strength	Elongation	Reduction in Area
8¼ × 8¼ × 20 in.	Bottom	237,000 psi.	296,000 psi.	7.4%	21.9%
	Top	238,500	294,500	6.5	16.0
10¾×11⅜×16½	Center	236,000	285,000	4.4	15.8
5 × 18 × 42	Center	233,000	287,000	3.6	7.8

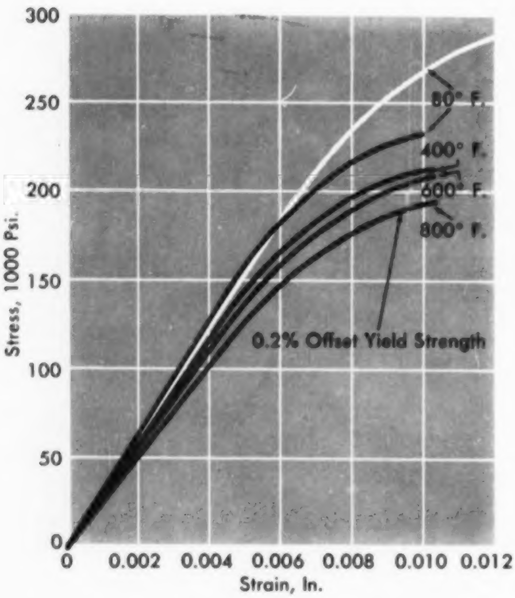


Fig. 4 – Stress-Strain Curves for H-11. The white curve indicates compression values; the other curves are tension stresses

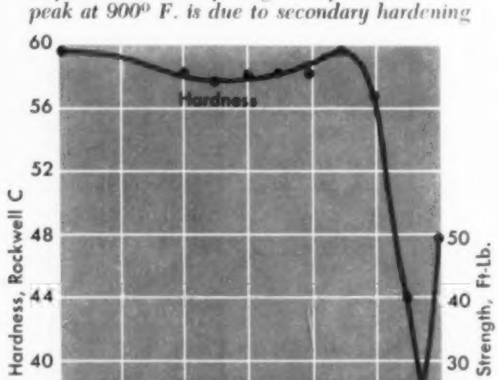
also reveal that yield strength in compression is appreciably higher (276,000 psi.) than yield strength in tension (225,000 psi.).

Impact Tests

Impact and hardness curves, shown in Fig. 5, reveal the effect of tempering temperature. Minimum impact strength (associated with secondary hardening) occurs at 950° F., while at 1000° F., the impact strength is 11.5 ft-lb. This value appears adequate; the high-strength aluminum alloys with a considerably lower impact strength have performed satisfactorily in aircraft for many years.

Actually, there are no generally accepted criteria for evaluating the impact strength of aircraft materials. However, "true" impact loads are generally avoided in aircraft design. Even landing and arresting gears which appear to undergo impact loading, contain various energy absorbing devices to prevent "true" impact load-

Fig. 5 – Variation of Hardness and Charpy Impact With Tempering Temperature. The peak at 900° F. is due to secondary hardening



ing. The greatest value of these tests is for comparison with other materials which have exhibited satisfactory service performance in similar applications.

Fatigue Strength

One problem we had to consider before using H-11 for sheet metal parts was decarburization. This reduces both load-carrying capacity and fatigue life. Decarburization is critical at the ultra-high strength levels due to greater loss in fatigue strength, particularly in the high-stress, low-cycle region.

treatment. (In fact, for the high stress, low-cycle condition there is no significant difference between these two curves from a practical standpoint.) Specimens machined *before* heat treatment, to remove mill decarburization, occupied an intermediate position between control specimens and ground specimens.

It is obviously impractical to machine or grind the formed sheet parts after heat treatment. Therefore, to insure maximum fatigue life, H-11 sheet is now being procured with a ground or sanded decarburization-free surface. The finish is equivalent to rms. 63 max.

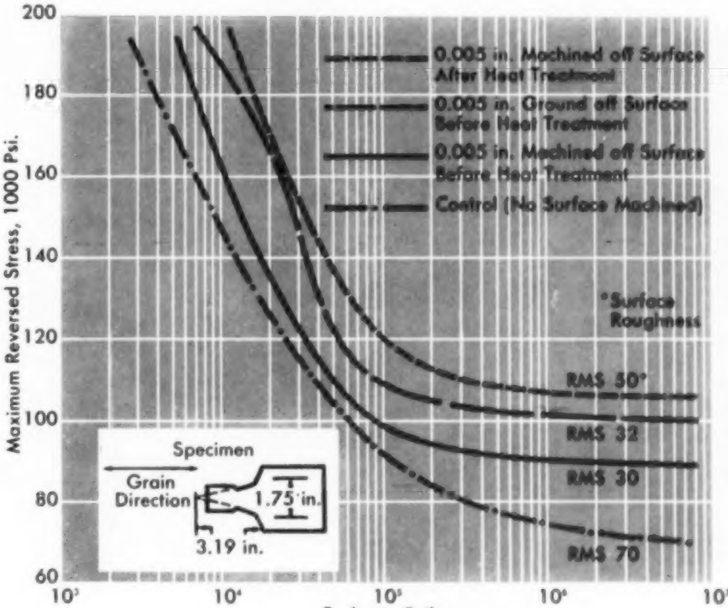


Fig. 6 – S–N Curves Showing Effect of Decarburization. Sheet 0.078 in. thick was tested at room temperature. All heat treatment was in a salt bath

Decarburization comes from two sources. Material received from the mill will have a slight amount though it is limited by specifications. Further, heat treatment during fabrication will also cause some decarburization in spite of the many precautions taken to prevent it.

To determine the effect of this decarburization, fatigue tests were made. Four conditions were studied. The curves shown in Fig. 6 indicated that specimens machined after heat treatment to remove all decarburization displayed a much higher fatigue strength than control specimens (those with decarburization). Specimens ground before heat treatment (to remove mill decarburization) exhibited fatigue strength nearly as good as the machined specimens after heat

Corrosion Resistance

Probably the greatest disadvantage of hot work toolsteel is its lack of corrosion resistance. Although it contains 5% chromium, its resistance is not greatly different from that of the low-alloy steels. Consequently, this alloy is not being considered for exterior applications, such as aircraft skins.

However, this lack of corrosion resistance has not prevented the use of H-11 in aircraft, since the alloy's great strength at elevated temperatures has made it invaluable for structural parts.

The special techniques used in forming, welding, heat treating and corrosion protection will be discussed in a second article which will appear next month.

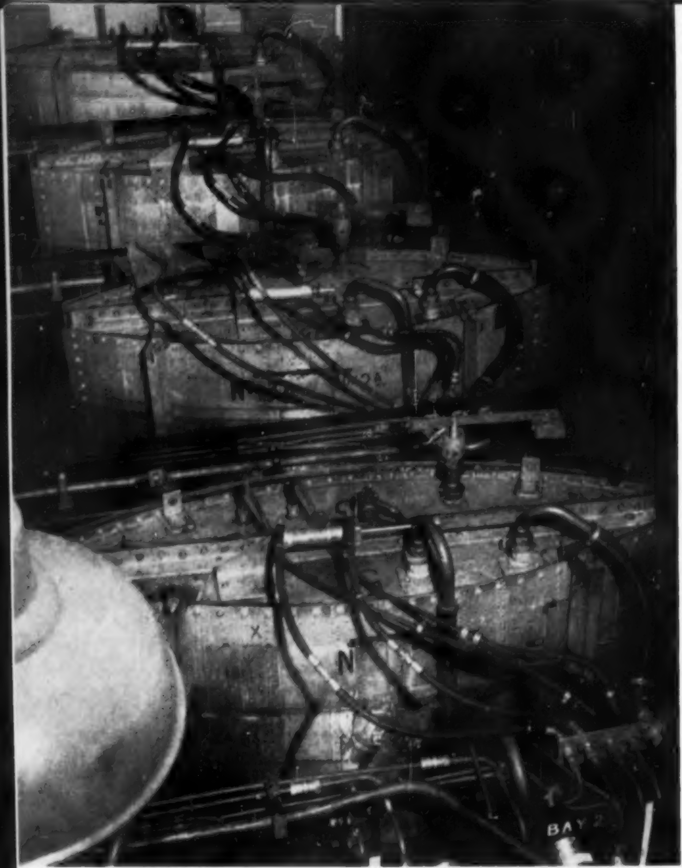


Fig. 1 – Fatigue Tests on Fuselage Panels. Panels in pairs were attached to steel edge spacers and interior pressure cycles applied hydraulically while immersed (for safety against rupture) in a compartmentalized water tank. All plates courtesy the de Havilland Co.

Designed to Fly ... High

*By TOM BISHOP**

Jet airliners ("Comets") met disaster in 1954. New Comets use metal of higher endurance and slow crack propagation, and the design is based on thousands of fatigue tests on material, joints, members, subassemblies, and completed structure. (T24, Q7, Al-b)

In May 1955 *Metal Progress* published an account by the present author of the disasters experienced in early passenger jets nicknamed "Comets" which caused them to be withdrawn from service, and triggered off one of the world's most exhaustive inquiries and metallurgical test programs, in which several thousands of static and fatigue tests have been carried out to determine the original faults and prove the safety of the new design.

The 1954 inquiry indicated that the disasters to these early aircraft (called Comet I) were due to fatigue failure of the cabin walls, starting at a rivet hole or other stress-raiser, and proceeding with explosive force from the expansion of the air inside the structure into the rarified atmosphere in which the craft was flying. The pressure differential (inside to outside of the fuselage) normally got as high as 8.25 psi. at the 30,000 to 35,000-ft. altitude reached every 20 min. in each flight, on the average. One Comet I, withdrawn from service and tested in a huge tank of water to simulate flying conditions, tore open after 3057 pressurized "flight cycles" at a stress which strain gages indicated to be 45,700 psi. max. per cycle, which was about 70% of the estimated static strength (65,000 psi.) of the material. This number of cycles to failure represented only about 1000 hr. flying time, normally logged in four months.

It became obvious that a successful jet airliner to fly at 35,000 ft. or even higher would have to be built with stronger material, or the design would have to be "beefed up" so working stresses would be lower, or both, and especial attention would have to be paid to stress-raisers either

*Consulting Editor of *Metal Progress*, John Miles & Partners (London) Ltd., London, England. The author acknowledges cooperation of the de Havilland Co. for data and illustrations.

inadvertent in fabrication or necessary in the design. This article will outline the test program which has insured that the present "generation" (Comet IV) conforms to these requirements by a large margin of safety. Thicker gage materials are used on the pressure cabin, while windows and cut-outs are redesigned to reduce the stress concentrations. The stress level has been lowered to such an extent that cracks should never occur during the service life of the aircraft, nor should they occur due to damage in service. Furthermore, the rate of propagation will be so slow that cracks can be seen in periodical inspections long before they could become dangerous to the aircraft.

The test program has demonstrated that no cracks occur in specimens, subassemblies or complete structure before a minimum of 60,000 reversals or 180,000 hr. of flying, and that any cracks appearing subsequently would not propagate seriously before a further 60,000 reversals, which is equivalent to a further 180,000 hr. (a total of 43 years of expected service at present flight schedules).

The operator of a modern airliner expects at least ten years' service from an aircraft operating at the rate of approximately 3000 hr. per year. Thus, the aircraft must be able to provide 30,000 hr. of flying time which means, for Comet IV, that it will cover some 15,000,000 miles. The tests indicate that the structure as now designed and built will serve 12 times that long without expensive replacements due to fatigue troubles.

Fuselage

The program was arranged so that it progressed in a natural sequence from small fatigue tests representing lap joints of the fuselage skin, to sections of the wall panels, then to complete portions of the fuselage, and finally to the complete fuselage itself.

Well over 2000 specimens representative of lap joints of the skin have been tested in the de Havilland laboratories at Hatfield, England. Segments of the fuselage were then constructed incorporating lap joints, window cut-outs, and other necessary details. These were tested in a water tank (Fig. 1). More than 60 Comet I and II and over 50 Comet IV panels have been tested in this tank.

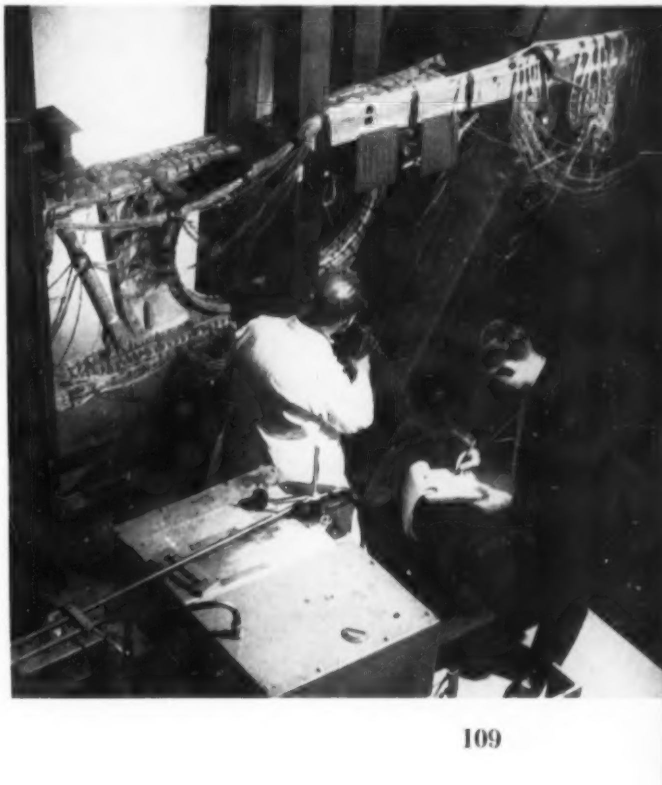
Edges of the panels were bolted to a square steel frame and pressurized with water while immersed in the tank. The pressure cycle was applied automatically. A multitude of strain gages were attached at strategic places on both the panels and steel ends. Some were pressurized with air to demonstrate that testing with water gave representative results.

To determine the rate of crack propagation, a specimen panel containing windows was tested. In the first period a differential pressure of 9.75 psi. was imposed to produce a crack in a reasonable time, but even so a crack did not appear until the equivalent of 186,750 flying hours had been reached. Thereafter the normal operating differential of 8.75 psi. per cycle* was maintained to measure the rate of growth. After the equivalent of a further 30,000 flying hours it was found that the crack in the specimen panel had extended by only 0.75 in.

Once the soundness of the new design had been proven in the above manner, three major fuselage sections were constructed and tested. The nose section, with cockpit canopy and windshield, completed 118,000 pressure cycles without failure, equivalent to 354,000 flying hours.

*The Comet I fuselage was tested under pressure cycles equivalent to 8.25 psi. The figure 8.75 psi. for the new series of tests represents a corresponding stiffening of the design requirements.

Fig. 2 – Comet IV Wing Spar in Fatigue Test. Loading cycle automatically simulates take-off, nine very strong wind gusts, and landing. No failure in 1,140,000 cycles



The second specimen consisted of the rearmost 26 ft. of the pressure cabin and included the passenger entry doors, a luggage door, the rear pressure dome, windows, escape hatches and other typical cut-outs. This portion completed the equivalent of 360,000 flying hours without any major failure of the structure. This fuselage section was then used to study crack propagation. A 3-in. crack was deliberately introduced, and 2000 pressure cycles, the equivalent of 6000 flying hours, could be applied to this section of the aircraft before the crack spread at the rate of 0.1 in. per load cycle.

The third specimen consisted of the center portion of the fuselage and wing struts section. In addition to the internal pressure loads, the effect of gusts striking the wings was simulated by hydraulic jacks, equivalent to the cumulative effect of all the gusts that the aircraft would be expected to experience during a flight. This specimen was subjected to 120,000 pressurizations together with 2,880,000 wing gusts, the equivalent of 360,000 hr. flying, without any failure of the major structure.

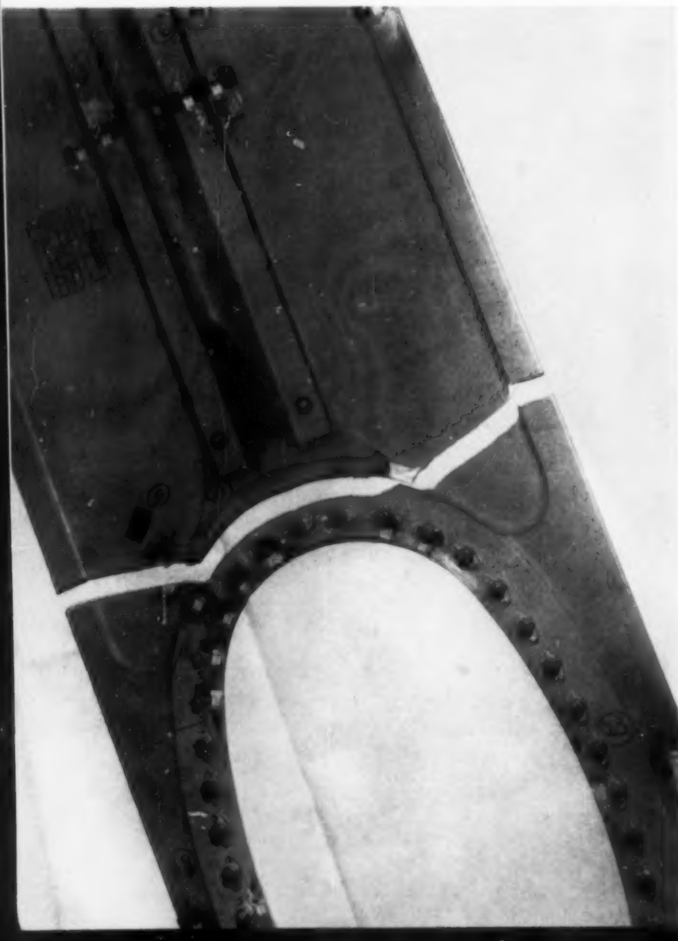


Fig. 3 – One of the Many Tests to Destruction. A portion of the Comet IV wing skin incorporating an inspection hole after fatigue test to failure

Wing Structure

The wing structure of the Comet IV was tested in a program similar to that described above for the fuselage, but the basis for estimating the fatigue loads was not pressurization but the frequency and magnitude of air gusts as the aircraft is in flight.

Loading – An instrument known as the "Fully Recording Accelerometer" has been developed at the Royal Aircraft Establishment which records the accelerations experienced by an aircraft together with its speed and altitudes, from which gust velocities can be calculated. Such measurements were taken on Comet I's when they were in service and on other aircraft and from them a "gust spectrum" has been built up. The wing structure must withstand the cumulative effect of this gust spectrum for the life of the aircraft with an appropriate factor of safety to allow for the scatter of test results – rather large in fatigue testing, as is well known.

Material – A major decision was to construct the lower booms of the wing spars and the bottom skin of the wings of Comet IV of alloy conforming to the American specification for 24 S rather than the British D.T.D. 546 B. Although the static strength is lower than that used in the earlier Comets (58,000 psi. min. for 24 S-T 4 versus 60,500 for the 546 B) and consequently involved a small weight penalty, its better fatigue properties could not be ignored.*

To find the best design for wing root joints, more than 130 samples have been tested in an Amsler fatigue machine. By using 24 S aluminum alloy, by careful control of the bolt fits with MoS_2 as an antifretting agent, and by tightening both with torque spanners, the fatigue life was increased from 300,000 gust reversals to 16,000,000 unbroken. This was a big step ahead. For a slight weight penalty to cover static strength the fatigue life is increased well over fifty-fold.

*In the *Metal Progress* article in May 1955 the endurance strength of bare 24 S-T 4 is quoted as 20,000 psi. for 500,000,000 cycles in reverse bending, whereas this stress is safe for only 100,000 cycles on D.T.D. 546 Alclad. Typical chemical analyses of the alloys are:

Element	24 S	D.T.B. 546 B
Copper	4.5	3.5 to 4.8
Iron	–	1.0 max.
Silicon	–	1.5 max.
Magnesium	1.5	0.6 max.
Manganese	0.6	1.2 max.
Titanium	–	0.3 max.

Tests on wing spar sections and complete spars (Fig. 2) in a 100-ton fatigue testing machine all gave satisfactory results. In Fig. 2 the test cycle includes loads representing take-off, nine gust cycles equivalent to $\pm$14.8 ft. per sec., and landing load. (In some other tests the loads represented gusts of 17.5 ft. per sec.)

When these tests were concluded in July 1957, the rear spar (Fig. 2) had withstood 1,140,000 cycles, representing 405,000 flying hours for Comet IV which, with a factor of safety of 5, indicates a "safe life" of 81,000 hr. with no cracks.

To insure a satisfactory fatigue life for the bottom surface of the wing, many hundreds of tests have been made on sample skin joints. Some specimens represented portions of the wing containing tank access doors. One of the latter, after failure, is shown in Fig. 3.

The Water Tank Test

As a final check on all the detailed testing above noted, the fatigue life of the whole aircraft is being checked in a comprehensive water-tank test, in which the entire fuselage is immersed in a huge rectangular water tank, so that pressure cycles can be safely imposed. The wings project through water-tight seals in the tank's walls, and simulated flight or landing loads and gust loads are imposed from vertical jacks and a system of equalizing beams.

For the Comet IV the most damaging gust is one of 13 ft. per sec. and 12 of these gusts represent the loading to which the aircraft is subjected during a 4-hr. flight. The cycle of loading for the water-tank test is a load representing the take-off (ground to level flight), followed by 12 loads arising from 13 ft. per sec. positive and negative gusts, during which sequence the fuselage is pressurized and depressurized, and finally the landing load applied to the whole structure completes the cycle.

It was noted at the outset that unit stresses in the new Comets would have to be reduced for safety. That this has been done is illustrated by the following table showing the stress at the end bolt hole of the front bottom stub boom on the respective aircraft (as measured by appropriate strain gages when tested in the tank as indicated above):

	Series I	Series II	Series III
Stress due to gravity in level flight	12,500 psi.	9800	5300
Stress due to gust of 10 ft. per sec.	4400	3400	2450
Stress due to gust of 1[illegible] ft. per sec.	5650	4400	3200

Fig. 4 – Comet III Fuselage After Static Test to Destruction

Static tests on the Comets have been going on continuously for the past ten years and the experience so gained has been incorporated in the Comet IV. As with fatigue testing, the number of static tests runs into thousands and covers all the basic structure. Test specimens range from small details to large portions of the structure with eventual tests carried out on complete wings and fuselage.

To enumerate and illustrate all these would require several issues of *Metal Progress* but the following list indicates some of the main components that have been tested and have met the design requirements:

All Class I castings and forgings.

Compression and shear panels (for design information).

Nose and main undercarriages.

Tailplane, fin, rudder, flaps and ailerons.

Wings and fuselage.

A Comet III fuselage, whose design was based on tests on compression panels and shear panels, was tested under its critical loading conditions and withstood 104% of its design load before failure (several times the maximum expected operational load). Figure 4 shows this fuselage after test.

Conclusion

It is hoped that this brief summary of the very extensive test program carried out to prove the Comet IV substantiates the belief of the de Havilland Co. that this aircraft has gone into service with a background of testing unsurpassed by any other aircraft.

Stress-Relief of Aluminum for Aircraft

By R. T. MYER, S. A. KILPATRICK
*and W. E. BACKUS**

Use of machined components instead of assemblies in aircraft has led to much research on stress-relief processes. Stretching, cold forging, and skin-pass rolling are successful, in descending order, in relieving stresses in heat treated aluminum alloy plates. (G23, G9, Q25; Al)

MUCH WORK has been done in the past several years on commercial methods for stress-relieving wrought aluminum products. The need for this activity has been generated chiefly by the aircraft industry's continued adoption of machined components to replace assemblies of small parts†. Large sections often warp badly when machined if they have not been stress-relieved previously.

We know, of course, that stress-relief is not the only way to solve the distortion problem. Much progress has been made in eliminating the need for machining. For instance, many parts are now chemically milled to enable better distortion control. Improved forging and extrusion techniques have reduced the amount of machining necessary. For example, various large forging and extrusion presses recently installed have made available no-draft or low-draft forgings, larger forgings and extrusions made to closer tolerances.

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†This has also led the Aluminum Association to devise additional codes for temper designations. Applied only to heat treatable alloys, three digits now follow the "T". As before, the first number indicates the basic temper. The next number is always "5" to denote that the alloys have been stress-relieved. The third digit indicates the mode of stress relief (1 – stretching,, 2 – compression, and 3 to 9 for any stress-relief method developed in the future). For example, the 7075 alloy mentioned in this article will be termed 7075-T 651 if solution treated, stress-relieved by stretching, and aged. If stress-relieved by skin-passing or cold forging (instead of stretching), it will be called 7075-T 652.

Furthermore, internal stresses may be beneficial under some circumstances. Compressive stresses in the surface increase fatigue life and resistance to stress-corrosion cracking, and decrease notch sensitivity. These other factors often provide a strong incentive to live with residual stresses.

In heat treatable aluminum alloys, the internal stresses created by casting, rolling, forging or extrusion are, for all practical purposes, relieved by heating to the solution heat treating range. Only those stresses created later (by quenching, finishing or other fabricating operations) may cause distortion during machining.

Stress-Relief Methods

The first appreciable progress came in the manufacture of plate, because machined skin sections were so prone to warp. For a time it was believed that repeated bending by roller leveling helped to stress-relieve plate. Theoretical calculations have shown that roller leveling plate of specified size and internal stress distribution could yield a substantially stress-free plate. But these same calculations showed that the particular setup would have to vary for each plate size and each different stress condition. These limitations are such that it is now generally agreed that roller leveling is not practical for stress-relieving heavy plate.

Real progress in stress-relieving coincided with Kaiser Aluminum's installation of a 3,000,000-lb. capacity stretcher at Trentwood, Wash. This was later increased to 5,000,000 lb., and more recently to 10,000,000-lb. capacity; it will now stretch 7075 plate with about a 200-sq.in. cross section. Two other aluminum producers have recently installed 16,000,000-lb. capacity stretchers, and a 30,000,000-lb. machine is now under construction (see Fig. 1). This machine

will stretch plate up to 6 in. thick, 160 in. wide and 720 in. long, and is to be used for general aluminum alloy plate products as well as stretcher stress-relieved material.

For many years, in making both die and hand forgings, manufacturers have tried to control distortion – that caused by quenching after solution heat treatment and that which occurs in later machining – by using modified quenching procedures. While aluminum alloys are usually quenched in cold water, many forgings require quenching in hot water – either at 140° F. or boiling. These practices have helped, but are far from solving the problem.

Stretching can be used on some hand forgings, but most cannot be handled by existing stretchers. However, a small reduction by cold forging after solution heat treatment will give satisfactory stress-relief. Consequently, this practice is quite generally specified for hand forgings. Adapting cold forging to stress-relieve die forgings is much more complicated, but is under investigation.

Cold rolling after solution heat treatment (a "skin-pass" reduction of about 2%, for example) also provides some stress-relief.

Thermal methods have been considered. Most conventional approaches to their use for heat treatable aluminum alloys disqualify themselves because the heat needed to relieve stress also adversely affects the properties. Other approaches include a cold quench technique and a "thermal shock" treatment. The reintroduction of heat at high rates for short times following quenching has been patented. Many have considered such treatments for aluminum alloys, but all such work is apparently still in the laboratory or development stage.

How Stresses Are Developed

The residual stresses in aluminum alloy parts are primarily those created by quenching after solution heat treatment. Before quenching, the plate has been "soaked" at a suitable high temperature (for example, 875° F. for 7075 alloy) long enough to equalize the temperature throughout the piece and dissolve the soluble alloying constituents. The hot section is then lowered directly into cold water. Since the surface cools more rapidly than the center of the piece, it contracts to a greater degree. Since the surface and center are not separated, they must retain equal lengths, and stresses are generated. The surface is in tension, the core in compression. The warmer, lower strength core material follows the colder surface material by deformation, and the stresses are great enough to cause plastic deformation. Now, when the surface metal reaches the temperature of the quenching medium, the core must cool still further and, therefore, contract further. This again results in stresses which are partially relieved by relative deformation between surface and core, and the piece warps. The final result is tensile stresses in the core, and compressive stresses at the surface.

Stretching in metal production (as distinguished from metal fabrication) involves gripping the ends of a plate, bar or extrusion and pulling axially. This pull creates uniaxial tensile stresses throughout the piece; stressing continues until the material yields and stretches plastically. In commercial stretcher stress-relief, any bucking is removed, and the length is increased by about 2½%. When the stretching force is removed, the piece springs back to about 102% of the original length, or a 2% permanent set. This figure is typical for production of stretcher stress-relieved plate.

The process can be illustrated by a tensile test stress-strain diagram. Figure 2 illustrates the surface and core stresses plotted separately against strain to help illustrate the mechanics of this process. The curve OS-OS shows stress distribution through the cross section of an "as-quenched" plate. At the start of stretching, obviously no elongation has occurred. It is therefore proper (on the stress-strain plot at right) to show the situation at the start by the point OS for the edges. Typical stress-strain curves for this particular alloy are then superimposed through these points. Next, apply enough tensile stress to lengthen the plate 1%. The core "fibers" are then represented by 1C and the outer fibers by 1S. The stress pattern

Fig. 1 – Sketch of 30,000,000-Lb. Plate Stretcher. Now under construction by Kaiser Aluminum at Ravenswood, W. Va., this machine will stretch a plate 6 in. thick, 160 in. wide and 720 in. long

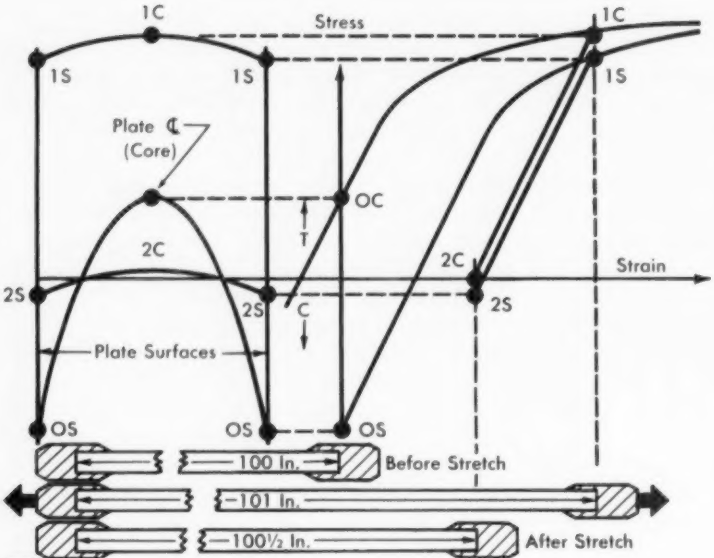


Fig. 2 – Diagram Illustrating Effect of Stretching on Internal Stresses. Stretching into the plastic range lowers residual stresses, but does not reverse their direction

becomes that shown by the left-hand curve (1S-1S). Most of the elongation has been plastic. Upon removal of the load, the plate shortens elastically – the stress levels are then represented by the points 2C and 2S, and the stress distribution by the line 2S-2S on the left. This stretching process always lowers both the stress level and the stress difference between surface and center.

In the cold forging method (following solution heat treatment), the part is pressed between flat dies. Usually these dies contact short sections of the piece. Starting at one end, successive portions are thinned by about 2% until the entire length has been cold worked. Cold forging introduces a controlled differential strain pattern to produce a stress pattern approximately equal, but opposite, to stresses induced by quenching.

This pattern cancels the original, and stress-relief results. The final pattern varies depending on the "bite-size" (the portion of the forging worked in one step) and the amount of cold forging reduction. From a practical viewpoint, a 2% nominal reduction is about the optimum value for most forgings.

Laboratory Tests

Some recent quantitative information has been obtained from a cooperative program carried on by Kaiser Aluminum and one of the aircraft manufacturers. A number of 7075 alloy plates, 2 in. thick, were produced by standard rolling, heat treating and quenching practices. Immediately after quenching and before aging, some of these plates were given various cold work treatments (by skin-pass rolling, stretching and cold forging), while others were retained as controls. Skin-passing and cold forging reduced the plate thickness by 2%, and the stretched material was elongated to a permanent set of 2%. This figure was selected because experience has shown that material stretched or forged to that degree will be relieved of most of its residual stresses. In support of this, Fig. 3 shows a graphical summation of data compiled by several aircraft manufacturers and two plate producers. The curve flattens out above 1½%, indicating that there is no substantial advantage in working material over 2%. Further, there are production problems when this is tried. For example, more working causes increased breakage in stretching, and increased variation in width due to necking down during stretching.

These experiments concerned practical aspects; they were designed to compare some current

Fig. 3 – Effect of Varying Amounts of Stretching on Internal Stresses. Above 1.5 there is little change; consequently, a 2% permanent set is usually applied in practice

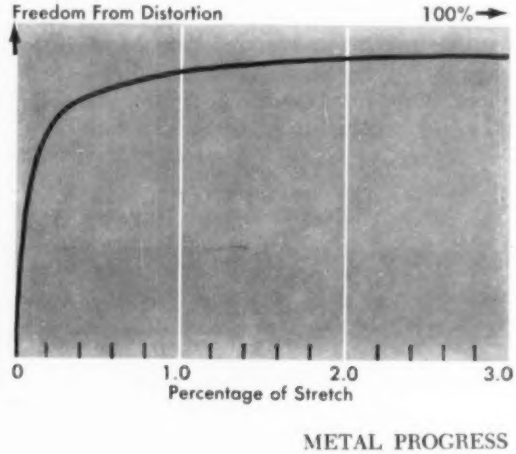
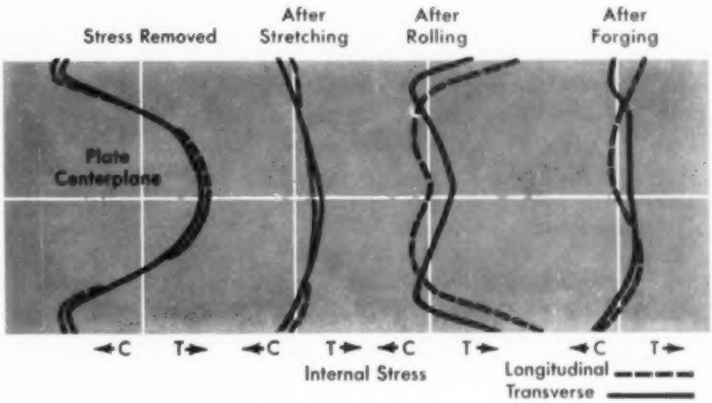


Fig. 4—Comparison of Stretching, Skin-Passing and Cold Forging. Stretching and cold forging reduce stresses appreciably, while skin-passing produces high tensile stresses at the surface



production methods for evaluating stress-relief against actual stress levels measured in the laboratory. Results obtained from the measurements were combined into standard stress-strain relationships, yielding data on the residual stresses in both transverse and longitudinal directions.

Figure 4 shows the effect of stretching, skin-pass rolling and cold forging. The left-hand diagram marked "Stress Removed" shows the stress distribution through the thickness of the plate when it has been normally quenched and artificially aged without intermediate cold work following heat treatment.

Stresses near the surface closely approach the yield strength of unaged material. If about 10% of the thickness is milled from one surface (as in conventional machining), much of the compressive load is relieved. Removal of this load, since it is far from the centerline, results in sizable warping. The machined surface becomes concave. It is obviously difficult to hold such material for accurate machine work.

The next figure shows the residual stresses after stretching and aging. A plate with such small residual stresses will be much less trouble to machine.

Next in line are shown stress patterns for plate which has been relieved by skin-pass rolling. It is apparent that the skin-pass does about as much harm to surface stresses as did the quenching operation. Furthermore, these stresses have been reversed in sign, being tensile rather than compressive. They are confined to a zone much nearer the surface than are the quenching stresses, however.

The right-hand figure demonstrates the stress-relief afforded by cold forging. Stresses are greatly reduced; however, there is a slight but real stress reversal at the surface just as in the skin-pass operation.

Summarizing these processes, stretching is the only method which *always* reduces the residual stresses but *never* reverses them. It is the most foolproof from the operator point of view. Also, both stretching and cold forging are appreciably better than skin-passing.

These findings have generally been confirmed by field experience. Continuing this test, Lockheed Aircraft Corp. evaluated plates by taking first a skin milling cut and then a rib milling cut on material from each group, and measuring distortion after the completion of each cut. For the skin cut, stretching and cold forging were about equally effective, while the skin-pass actually appeared to increase the distortion tendency. This result is predictable; as mentioned before, laboratory tests revealed rather high surface stresses in skin-passed material. For rib cutting, all three methods had improved the material, but the stretched material was markedly superior to either forged or rolled material.

These treatments also affect mechanical properties. Further testing showed that stretching, cold forging and skin-passing all increased the longitudinal tensile yield strength. Compressive yield strength is lower than the tensile yield in stretched material, while the opposite is true for skin-passed or cold forged material. In material with no stress-relief, the compressive yield strength is higher than the tensile yield strength. Material stretched as little as 1% shows compressive yield strength values slightly lower than the tensile yield strength values; further stretching has little additional effect.

Still another evaluation shows how mechanical properties are affected by cold forging to stress-relieve hand forgings. Both longitudinal and transverse tensile yield are increased slightly although the metal's transverse tensile yield drops somewhat. Probably the most significant effect lies in the rather pronounced difference

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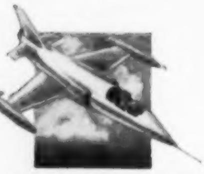

Stainless Steel for Hot Aircraft

AM 350 and AM 355... Properties and Heat Treatment

By R. A. LULA*

Two new high-strength stainless steels have similar compositions but different properties. Chromium and carbon are adjusted so that one grade contains delta ferrite while the other is completely martensitic. Both steels are readily formed when annealed; heat treatment imparts high strength with good ductility at room and elevated temperatures. (Q-general, 2-62; SS)

SEMI-AUSTENITIC stainless steels are used in many of today's aircraft and missiles. They have good formability and can be hardened to a high strength level at temperatures low enough to minimize distortion and oxidation. Two steels of this type are AM 350 and AM 355. Their compositions are similar; however, differences in structure and mechanical properties qualify them as distinctly different materials.

	AM 350	AM 355
Carbon	0.10	0.15
Chromium	16.50	15.50
Nickel	4.25	4.25
Molybdenum	2.75	2.75
Nitrogen	0.10	0.10
Silicon	0.30	0.30
Manganese	0.75	0.75

In the annealed condition, the alloys are austenitic, while in the hardened state they are martensitic. As annealed, their formability and weldability are as good as other austenitic steels. After hardening, they have the strength of martensitic steels. Their corrosion resistance is similar to conventional austenitic stainless steels.

Today, these two grades are available in all the forms commonly used in the fabrication of jet engines and airframes – sheets, plates, bars, forging billets, wire and castings. Heat treatments vary, depending on the form being processed.

Since annealed AM 350 and 355 both have an austenitic matrix, they have most of the characteristics of the standard austenitic steels. AM 350 has 10 to 20% delta ferrite while AM 355 contains little or none of this constituent. When the alloys are rapidly cooled from above about 1875° F., all carbides are in solution and the austenite has its maximum stability. Even at this stage these alloys are less stable than Type 301 – the least stable of the chromium-nickel austenitic stainless steels. Re-annealing below 1875° F. will reject from solution additional carbon as chromium carbides. This further decreases the stability of austenite.

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If we choose the M_s temperature as a measure of stability of austenite, then, as shown in Fig. 1, the M_s increases from -100 to 250° F. when the annealing temperature is decreased from 1900 to 1450° F. Thus, when using an annealing temperature above 1800° F., the M_s is below room temperature, and the steel is austenitic. Annealing 10 min. in range 1700 to 1800° F. gives an austenitic structure with a small amount of martensite. However, this structure can be transformed almost entirely to martensite if the temperature is lowered to about -100° F.

If annealing is done below 1700° F., the M_s continues to increase. For example, a 250° F. M_s corresponds to a 1450° F. anneal. The M_s attains the highest values with a 1350 to 1450° F. anneal and reaches an even higher temperature – about 300° F. – if annealing time increases to 3 hr. as shown by Curve B in Fig. 1. In this instance, the M_s is high enough for the steel to transform substantially to martensite on cooling to room temperature. This way of controlling the M_s temperature is the basis of heat treating methods for AM 350 and AM 355.

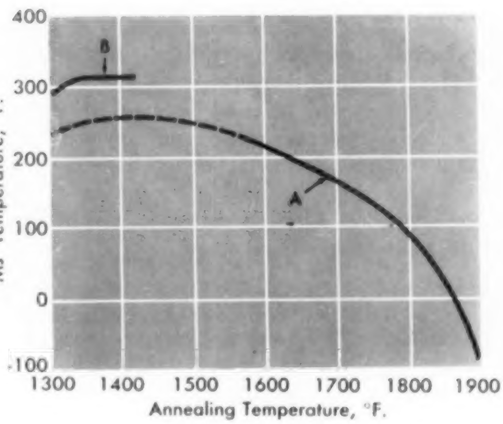


Fig. 1 – Graph Showing M_s as a Function of Annealing Temperature. Upper curve illustrates effect of long annealing times

Hardening Treatments

Three methods of heat treatment are used which are derived from this behavior:

1. When annealed above 1850° F., the steels are austenitic. This is their best condition for forming and welding.

2. Re-annealing at 1700 to 1750° F. raises the M_s slightly above room temperature so that refrigeration at -100° F. transforms austenite to martensite. This is the preferred method.

3. Heating at 1300 to 1400° F. raises the M_s to about 300° F. Upon cooling to room temperature, transformation to martensite occurs as in conventional martensitic steels. This is the second hardening treatment.

As can be noted above, both hardening methods are preceded by an annealing treatment which conditions the austenite for transformation to martensite. Conditioning at 1700 to 1750° F. results in less carbide precipitation compared to the 1300 to 1400° F. anneal. This means more carbon is retained in solution. Thus, conditioning at 1700 to 1750° F., followed by refrigeration, gives a higher-carbon martensite with greater tensile strength. Because carbide precipitation is faster at the higher temperature (1700 to 1750° F.), conditioning can be done in a shorter time. The corrosion resistance in the hardened state is also better with the 1700 to 1750° F. anneal because the distribution and quantity of carbides are more favorable than for the 1300 to 1400° F. treatment, which is within the sensitizing range for austenitic stainless steels.

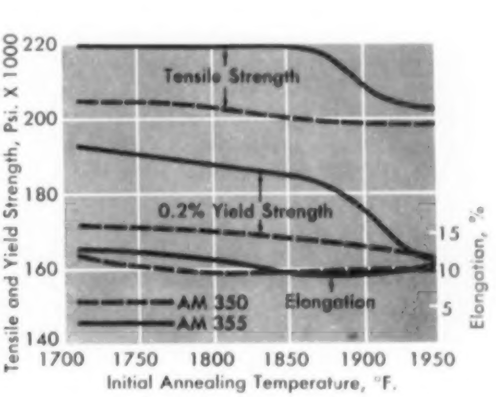


Fig. 2 – Effect of Annealing on the S.C.T. Properties of AM 350 and AM 355

Both hardening treatments are completed by tempering at 850 to 1000° F. The term "tempering" is not entirely descriptive because several metallurgical changes cause an appreciable increase in yield strength. An 850° F. temper gives the highest tensile strength. A 1000° F. temper is used primarily for bar and forgings to improve impact strength and ductility. It also decreases the hardness to a level which is machinable.

In this article we will refer to the first-hardening treatment as the S.C.T. (subzero cooled and tempered) treatment and the second as the D.A. (double aged) treatment.

Table I – Average Tensile and Stress-Rupture Properties of AM 350 and AM 355 in Sheet Form

Alloy	Treatment	Tensile Strength	Yield Strength	Elongation in 2 In.	Stress for Fracture in 100 Hr.	Stress for Fracture in 1000 Hr.
AM 350	As annealed	145,000 psi.	60,000 psi.	40.0%	—	—
AM 350	S. C. T.	200,000	172,000	13.0	—	—
AM 350*	S. C. T.	190,000	130,000	11.0	185,000†	181,000†
AM 350	D. A.	185,000	150,000	12.0	—	—
AM 355	Annealed	185,000	56,000	30.0	—	—
AM 355	S. C. T.	215,000	185,000	12.0	—	—
AM 355*	S. C. T.	200,000	139,000	10.0	187,000†	182,000†

*Testing temperature, 800° F.; others tested at room temperature. †850° F. temper.

Differences Between AM 350 and AM 355

The composition of AM 355 differs from AM 350 only in carbon (higher) and chromium (lower). As a result, AM 355 is practically free of delta ferrite while AM 350 contains 10 to 20%, as previously noted. The change in carbon and delta ferrite account for the variation in carbide precipitation and the different mechanical properties of the two alloys. Figure 2 shows how annealing (when applied to cold rolled material) influences tensile properties of typical heats of AM 350 and AM 355 conditioned at 1710° F. for 10 min. and hardened by the S.C.T. treatment.

The tensile strength of AM 355 in the hardened state is higher than AM 350 if the annealing temperature (prior to the 1710° F. conditioning treatment) does not exceed 1875° F. Above this, the properties of AM 355 fall off rapidly and the strength advantage over AM 350 is lost.

The microstructure of AM 350 in the hardened state is markedly different from that of AM 355. Figure 3 shows the structure of a typical heat of AM 350 annealed at 1950° F., then conditioned at 1710° F., and hardened by the S.C.T. treatment. The carbides precipitate at 1710° F. almost entirely at the delta ferrite-austenite interface.

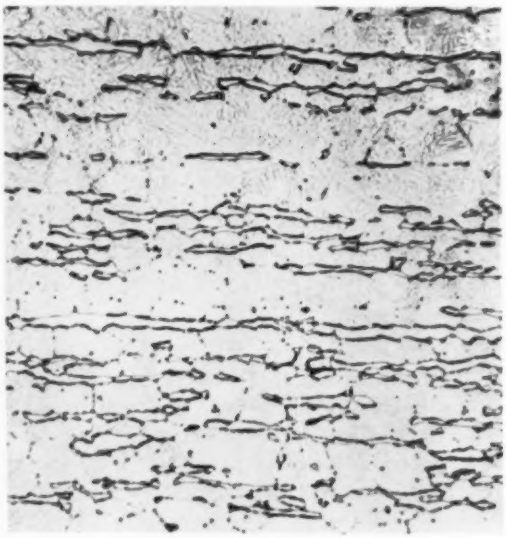
When the same heat is annealed at 1850° F. (after cold rolling) and hardened in the same manner, there is practically no difference in the two structures. The properties given in Fig. 2 are unchanged for either annealing temperature.

Figures 4 and 5 show the contrast in structure of AM 355 after undergoing the same treatments as above (that is, 1850 or 1950° F. anneals after cold rolling, conditioning at 1710° F. and S.C.T. hardening). The structure in Fig. 4 shows a uniform carbide dispersion while that in Fig. 5 shows a heavy carbide precipitation at grain boundaries and grain coarsening resulting from the higher (1950° F.) anneal. The tensile strength of AM 355 decreases substantially when the annealing temperature is increased from 1850 to 1950° F., as shown in Fig. 2. To take advantage of its higher strength properties, AM 355 must be annealed at about 1875° F.

AM 350 and AM 355 in Sheet Form

AM 350 in sheet form is annealed at 1950° F. which is above the precipitation range for carbides. A broad temperature range (±50° F., or even more) can be used because delta ferrite prevents grain coarsening, and no other important changes occur in this range. Ductility of the annealed sheet is suitable for severe forming. Re-annealing during forming is possible using the same temperature range.

Fig. 3 – Delta Ferrite Stringers in Hardened AM 350. This specimen was previously annealed at 1950° F.; if prior annealing is done at 1850° F., the structure is not changed. Compare with Fig. 4 and Fig. 5. 500 ×



Two hardening methods can be used: the S.C.T. treatment – preceded by a conditioning treatment at 1710° F. – and the D.A. treatment, as follows:

S.C.T. Treatment for AM 350 – 1710° F.; 3 hr. at −100° F.; 3 hr. at 850 to 1000° F.

D.A. Treatment for AM 350 – 3 hr. at 1375 to 1475° F.; cool to 60° F.; 3 hr. at 850 to 1000° F.

AM 355 – The annealing temperature is more critical since it has to be slightly below the solubility limit for carbides, but still high enough to produce maximum possible ductility. These conditions are answered by annealing at 1875 ±25° F. Because of this lower annealing temperature, AM 355 is less stable than AM 350 and has slightly lower ductility. The AM 355 grade is currently hardened by the S.C.T. treatment shown above for AM 350. AM 355 can also be hardened by the D.A. method, but conditioning at 1710° F. is necessary to insure consistent properties. Table I shows average tensile and stress-rupture properties of the alloys.

Heat Treating AM 355 Bar Stock

Heat treatments now used commonly for bar stock are not the same as for sheet. This is because bar stock should have good machinability rather than good forming characteristics. Austenite, particularly that which work hardens rapidly, is difficult to machine. On the other hand, martensite up to about Rockwell C-40 is readily machinable. For this reason, AM 355 bar stock is supplied with a 1375 to 1475° F. treatment (applied after forging) to produce an untempered martensitic structure. For best machinability, this is followed by overtempering at 1050 to 1100° F.

To harden, austenitize at 1710 or 1750° F. and follow by the S.C.T. treatment with an 850 to 1000° F. temper. Compared to the 850° F. temper, which shows the highest tensile strength (216,000 psi.), the 1000° F. temper has better impact strength (45.5 ft-lb.), ductility (57% reduction in area) and machinability.

AM 355 in bar stock form (see Table II for typical properties) is heat treated almost as a straight martensitic stainless steel. The high chromium and molybdenum content of AM 355 confers corrosion resistance equivalent to that of austenitic stainless steels. Weldability is also better. Conventional martensitic stainless steels will harden in the weld and heat-affected zone and form a hard, brittle area which may crack. The higher alloy content of AM 355 will cause the austenite formed during welding to be retained to room temperature; this produces a ductile weld. After conditioning, the weld zone can be hardened nearly to the same level as the base metal.

Cold Rolled AM 350 and AM 355

Designers of aircraft continually call for higher strength stainless steel, and one steel mill answer is cold rolling. Type 301, already available in

Fig. 4 – Martensitic Structure of AM 355. Prior annealing is at 1850° F. 500 ×

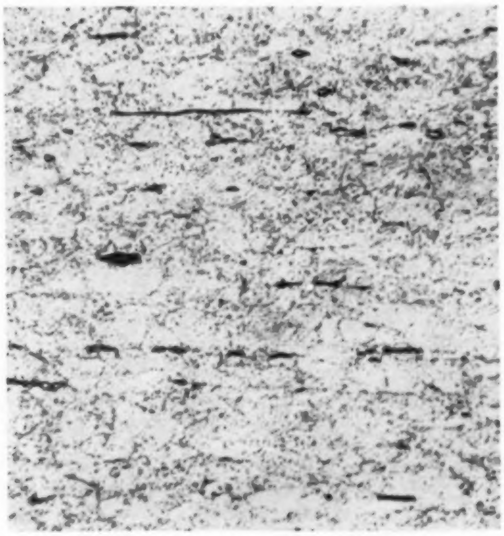


Fig. 5 – AM 355 Hardened as for Fig. 4 Except That Prior Annealing Is at 1950° F. Note grain coarsening and grain-boundary carbide precipitation. 500 ×

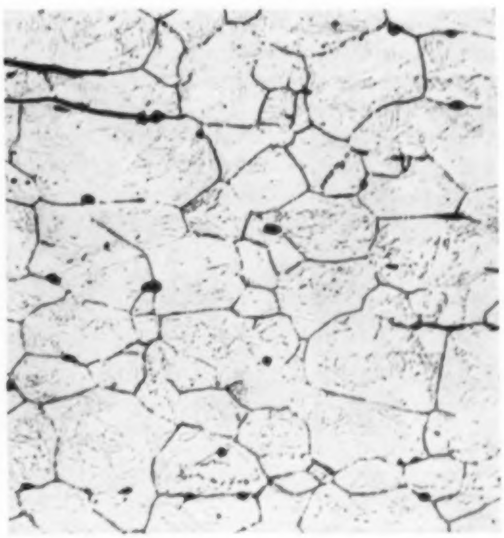


Table II – Mechanical Properties of AM 355 Bar Stock, S.C.T. Treatment

Testing Temperature	Rockwell Hardness	Impact Strength*	Tensile Strength	Yield Strength	Elongation	Reduction in Area
75° F.†	C-48	20.0 ft-lb.	216,000 psi.	182,000 psi.	19.0%	38.0%
800†	—	—	198,000	139,000	11.0	35.0
75	40	45.5	186,000	171,000	19.0	57.0
800	—	—	140,000	128,000	15.0	53.0

*Charpy V-notch test. †850° F. temper; others are 1000° F. temper.

Table III – Typical Tensile Properties of Cold Rolled AM 355

	AM 355 CRT*		AM 355 SCCRT†	
	Longitudinal	Transverse	Longitudinal	Transverse
Tensile strength (70° F.)	235,000 psi.	235,000 psi.	295,000 psi.	295,000 psi.
Tested at 800° F.	185,000	190,000	250,000	255,000
Yield strength (70° F.)	215,000	200,000	290,000	280,000
Tested at 800° F.	150,000	150,000	235,000	255,000
Elongation in 2 in. (70° F.)	20.0%	16.0%	3.0%	2.5%
Tested at 800° F.	8.0	7.0	2.5	4.0

*Annealed, cold rolled 20 to 30%, tempered at 700 to 900° F.
†Annealed, given refrigeration treatment, cold rolled 20 to 30%, tempered at 700 to 900° F.

cold rolled tempers up to about 200,000 psi., can be severely cold rolled up to 280,000 to 300,000 psi. However, AM 350 and 355 seem to be more suitable for very high strength levels. The rapid increase in strength produced by cold rolling both AM 355 and 301 is mainly due to martensite formation and work hardening. Since the austenite of AM 355 is less stable than that of Type 301, a larger percentage of martensite will be formed. Also, the martensite in AM 355 has more carbon than the martensite in Type 301. For both reasons, AM 355 can develop higher strength than 301 by cold rolling, or it can develop the same strength with a much smaller amount of deformation. The latter factor cannot be overlooked since the ductility, directionality, and maximum temperature of use of the cold rolled products all deteriorate with more cold rolling. At the same strength level, AM 355 will have better ductility and less directionality than Type 301.

Tensile properties of two AM 355 tempers, cold rolled 20 to 30%, are shown in Table III. Strengths equivalent to these could be developed in Type 301 only from selected compositions with roughly 50% and 80% reductions, respectively. AM 355 can actually develop strength over 300,000 psi. with more cold rolling.

AM 355 Castings

In castings, the composition and heat treatment were modified so as to attain optimum mechanical properties by a simple heat treatment. A nominal casting composition is 0.10 C, 15.0 Cr, 4.20 Ni, 2.30 Mo, 0.80 Mn, 0.60 Si, 0.09 N.

Long homogenizing at 2000° F. is needed to eliminate coring and decrease the delta ferrite formed on cooling after solidification. After homogenizing, castings which do not require optimum machinability are conditioned or annealed at 1750° F. and given the S.C.T. treatment (see Table IV for properties). If good machinability is needed, castings, like bars, have to be hardened and overtempered. After machining, castings are hardened as indicated after the homogenizing treatment.

Table IV – Average Mechanical Properties of AM 355 Castings*

Testing Temperature	Tensile Strength	Yield Strength	Elongation in 2 In.	Reduction in Area
70° F.	220,000 psi.	175,000 psi.	15.0%	35.0%
800	195,000	135,000	12.0	28.0
900	183,000	125,000	12.0	25.0

*Homogenized, annealed at 1750° F. and tempered at 850° F.

Stainless Steel for Hot Aircraft

PH 15-7 Mo . . .

More Strength at Elevated Temperatures

By M. W. MARSHALL
*and HARRY TANCZYN**

Addition of 2% molybdenum to 17-7 PH greatly enhances the mechanical properties of the original stainless steel. The new stainless, known as PH 15-7 Mo, can withstand up to 1000° F. in jet airframes and missiles. (Q-general, 2-62, 2-60; SS, *Mo*)

During the past eight years, thousands of tons of Armco 17-7 PH stainless steel have been used as a structural material for airframe components, skins and honeycomb panels in fighter aircraft, bombers and missiles. In general, temperature has been limited to 600° F. in these applications. However, with the rapid advance in jet-power technology, new materials designed for service to 1200° F. are required for airframes. One such stainless steel is PH 15-7 Mo developed recently by Armco Steel Corp. This new precipitation hardening stainless steel has excellent tensile and compressive yield strengths with marked resistance to creep up to 1000° F.

*Mr. Marshall is supervising research metallurgist at Armco Steel Corp., Middletown, Ohio, and Mr. Tanczyn is senior research engineer at the Armco plant in Baltimore, Md.

This stainless steel is essentially an improvement on 17-7 PH. The nominal compositions are quite similar, as shown below:

	17-7 PH	PH 15-7 Mo
Carbon	0.07%	0.07%
Manganese	1.00 max.	1.00 max.
Phosphorus	0.04 max.	0.04 max.
Sulphur	0.04 max.	0.04 max.
Silicon	1.00 max.	1.00 max.
Nickel	7.00	7.00
Chromium	17.0	15.0
Molybdenum	—	2.25
Aluminum	1.20	1.20

17-7 PH was discussed in *Metal Progress*, July 1956, p. 94. In that article, details of the pre-

Table I – Properties of Steel Plate, Sheet and Strip

	Condition		
	A	TH 1050	RH 950
Tensile strength	150,000 psi. max.	190,000 psi. min.	225,000 psi. min.
Yield strength, 0.2% offset	65,000	170,000	200,000
Elongation in 2 in.			
0.020 to 0.1874 in. thick		5% min.	4% min.
0.010 to 0.0199		4	3
0.005 to 0.0099		3	2
0.0015 to 0.0049		2	1

Table II – Effect of Prior Creep Stress on Room-Temperature Properties

Prior Creep Variables			Tensile Strength	Elongation in 2 In.	Rockwell Hardness
Temperature	Stress (1000 Hr.)	Permanent Set			
75° F.	0 psi.	0%	248,000 psi.	6.0%	C-48
600	125,000	0.08	270,000	4.5	52
700	120,000	0.12	280,000	4.5	53
800	110,000	0.13	291,000	4.0	54
900	70,000	1.08	262,000	4.0	52

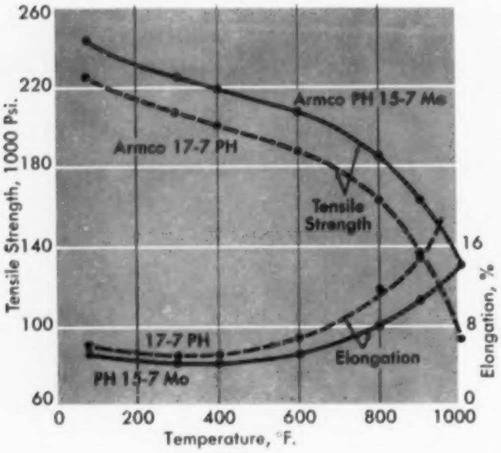


Fig. 1 – Comparison of Short-Time Transverse Tensile Properties of Two Precipitation Hardening Alloys in Condition RH 950. Note the improvement imparted by the molybdenum

cipitation hardening heat treatments (termed "Condition TH 1050" and "Condition RH 950") were described; these same treatments are used for PH 15-7 Mo, namely:

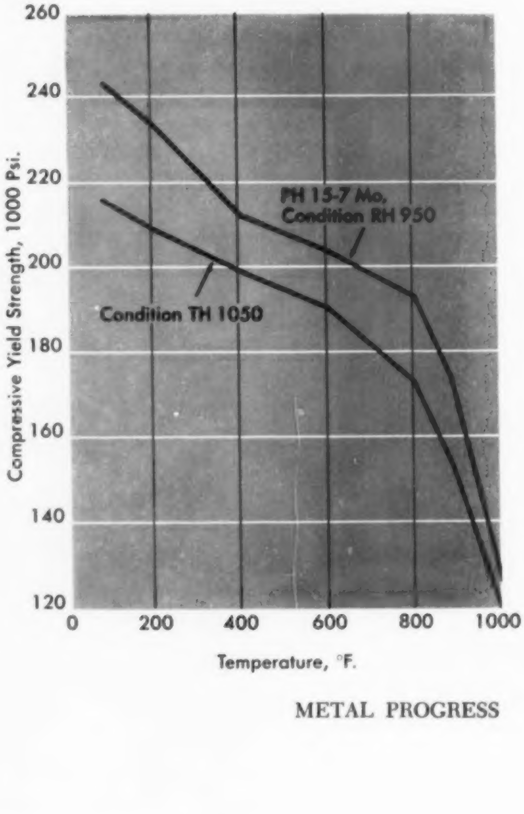
	TH 1050	RH 950
Austenite conditioning	1400° F., 90 min.	1750° F., 10 min.
Cooling	to 60° F., in 1 hr.	to −100° F., hold 8 hr.
Precipitation hardening	1050° F., 90 min.	950° F., 60 min.

Sheet, strip, plate and other mill products are supplied in the solution-annealed condition (termed "Condition A"). After forming, drawing or machining to the desired structural shape, the heat treating sequences above produce the high mechanical strengths shown in Table I. During either of these treatments, a net dimensional expansion of approximately 0.004 in. per in. occurs. In the annealed condition, the ductility of PH 15-7 Mo permits fabrication by standard methods such as stretch forming and drawing.

The marked improvement in short-time elevated-temperature strength of PH 15-7 Mo over 17-7 PH in Condition RH 950 is shown in Fig. 1. It is apparent that at any given temperature PH 15-7 Mo has a tensile strength approximately 20,000 psi. above that of 17-7 PH. Compressive yield strength is also important to the designer. Figure 2 shows the compressive yield strength of PH 15-7 Mo in Conditions TH 1050 and RH 950 at temperatures up to 1000° F.

For piloted aircraft, the ability of a material to sustain high loads with limited plastic strain over long periods of time is a vital factor to design engineers, and 1000-hr. creep test data are thus required. However, a different criterion

Fig. 2 – The New Steel Has Excellent Compressive Properties. This factor is important to airframe design



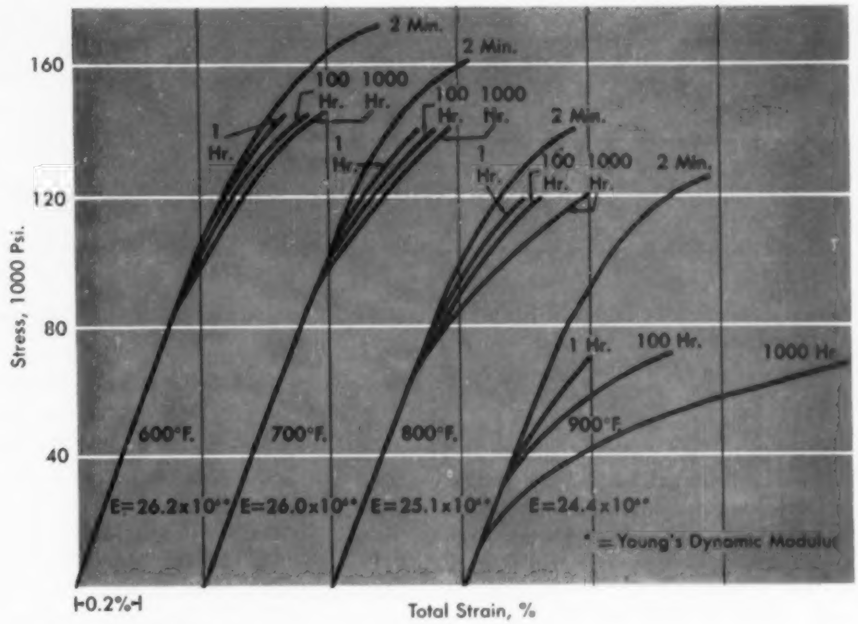


Fig. 3 – Creep Data for PH 15-7 Mo (Condition RH 950). Total strain has been adjusted to indicate modulus values

is applied in missile design since the steel must withstand exceptionally high loads for short times. Here, test data for periods of 2 min. or shorter are needed. Long and short-time creep data are presented in Fig. 3.

The data in Table II show that the room-temperature strength of PH 15-7 Mo sheet (Condition RH 950) is increased considerably by previous exposure for 1000 hr. at 600° F. under 125,000 psi. load. This pattern, which is like that obtained with 17-7 PH, follows for similar exposures at 700, 800 and 900° F., under loads of 120,000, 110,000 and 70,000 psi., respectively. This increase in strength occurs with only slight reduction in tensile ductility.

Table III shows the stress-to-rupture strength and the short-time tensile properties of PH 15-7 Mo sheets in Condition RH 950. Another factor of great concern to the design engineer is the ability of aircraft parts to retain their shapes permanently. Figure 4 compares the two alloys in this respect. Here, PH 15-7 Mo also improves on 17-7 PH. For example, at 600° F., PH 15-7 Mo stressed at 130,000 psi. for 1000 hr. permanently deforms only 0.1% while 17-7 PH under the same load conditions permanently deforms 0.2%. Also, at 800° F. it is readily seen that under the same limiting permanent deformation (0.1 or 0.2%) PH 15-7 Mo will sustain three times the load of 17-7 PH.

Material in this condition (Condition C) is hardened at the mill by considerable cold reduction. Final hardening at 900° F. (to Condition CH 900) for 1 hr. develops a tensile strength of 265,000 psi. with excellent elastic properties.

Fig. 4 – Comparison of Load-Deformation Behavior for the Two Armco Alloys

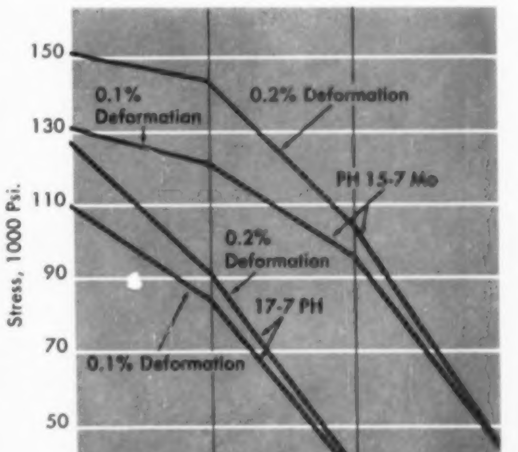


Table III – High-Temperature Properties of PH 15-7 Mo, Condition RH 950

Test Temperature	Short-Time Properties		Stress-Rupture Strength	
	0.2% Yield Strength	Tensile Strength	100 Hr.	1000 Hr.
600° F.	174,000 psi.	205,000 psi.	202,000 psi.	200,000 psi.
700	162,000	197,000	193,000	191,000
800	154,000	184,000	174,000	171,000
900	130,000	161,000	125,000	108,000

This product has found wide acceptance in parts such as springs, valve disks and diaphragms that require little or mild forming operations.

Fabrication

Preliminary tests indicate that PH 15-7 Mo can be freely substituted for 17-7 PH with no changes in fabricating procedures. For example, studies using simulated brazing cycles in air atmosphere show that high strengths are developed in PH-15-7 Mo with the same heating and cooling cycles used for 17-7 PH. Corrosion resistance of the two alloys is also comparable in Conditions RH 950 and TH 1050. They resist corrosion better than hardenable stainless steels such as Types 410, 420 and 431, but not as well as Type 302 (18-8) stainless steel. In the hard temper, Condition CH 900, PH 15-7 Mo exhibits its best corrosion resistance to marine atmosphere; it is then comparable to Type 302 stainless steel.

PH 15-7 Mo can be welded with the same process used for 17-7 PH. Higher strengths in inert-gas welded joints are obtained than with 17-7 PH in the same condition of heat treatment. Raising the final hardening temperature from 1050 to 1100° F. will increase the ductility of welded joints in the PH 15-7 Mo steel.

Comparison With Other Aircraft Material

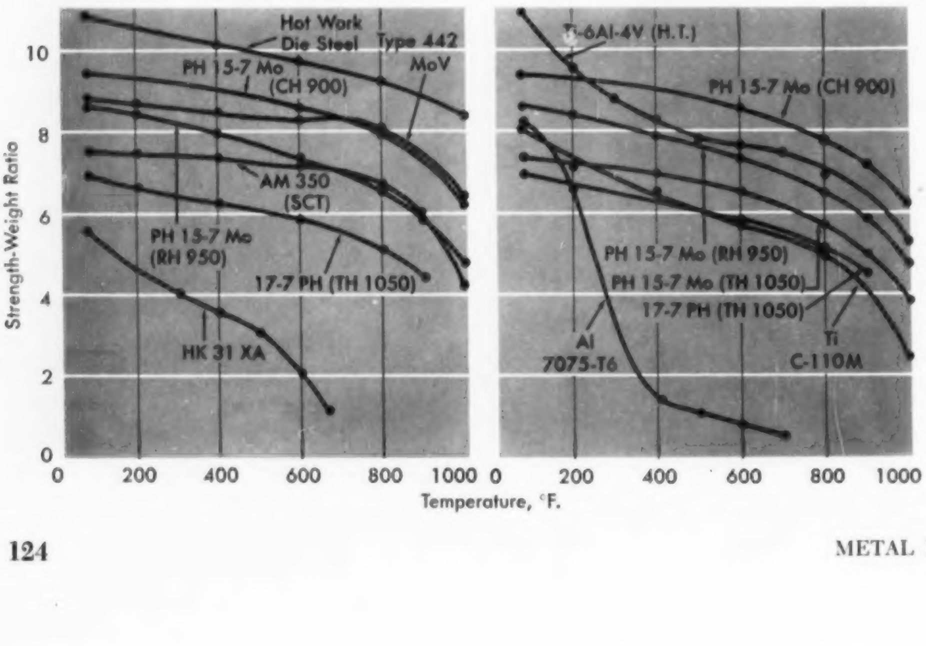
This article would be incomplete if comparison were not made with other commercially available high-strength heat resisting materials. Data are based on the following densities (lb. per cu. in):

17-7 PH stainless steel	0.276
AM 355 stainless steel	0.286
PH 15-7 Mo stainless steel	0.277
6Al-4V titanium alloy	0.161
C-110 M titanium alloy	0.171
7075-T 6 aluminum alloy	0.101
Type 422 MoV stainless steel	0.279
AM 350 stainless steel	0.286
5% Cr hot work die steel	0.282 (est.)
HK 31 XA magnesium-thorium	0.065

Aircraft engineers frequently use ultimate tensile strength as the basic design criterion for at least 30% of the airframe structure. Compressive yield strength is the determining property for 40% of the structure, while stiffness (based on elastic modulus) is considered the controlling factor in the remaining 30% of the airframe.

Strength-weight comparisons of short-time

Fig. 5 – Comparison of Tensile Strengths for Several Airframe Materials. (Ratio of strength in psi. to density in lb. per cu.in. × 100,000)



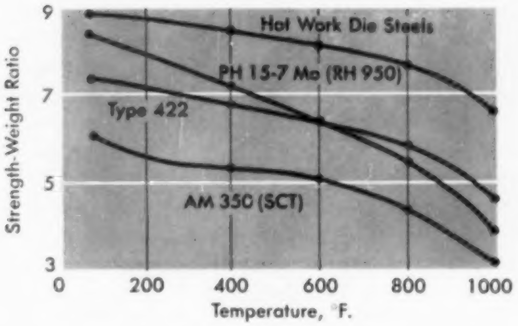


Fig. 6 – Yield Strength Comparisons for Some Airframe Materials

ultimate tensile strengths are shown in Fig. 5. PH 15-7 Mo in Condition CH 900 (hard temper, heat treated condition) compares favorably with other sheet materials for airframes and missiles throughout the temperature range up to 1000° F. However, as mentioned previously, in this condition PH 15-7 Mo has limited cold forming quality, and comparison should be made possibly in the RH 950 condition where currently used fabricating procedures can be applied. Here, Ti-6Al-4V (H.T.) and PH 15-7 Mo are quite comparable; the titanium alloy possesses slightly higher strength. The 5% Cr hot work die steels and Type 422 MoV have higher strength-to-density than any of these materials.

Some aircraft engineers base airframe design on short-time yield strength. In Fig. 6, yield strength-to-weight comparisons show that the hot work die steels have a noticeable strength advantage over PH 15-7 Mo and Type 422. However, these latter steels compare favorably in the 400 to 800° F. range. Figure 7 shows that the compressive yield strength-to-density ratio of PH 15-7 Mo (Condition RH 950) and Ti-6Al-4V (H.T.) are comparable in the 600 to 1000° F. temperature range, and are considerably higher than either 17-7 PH (Condition TH 1050) or titanium C-110 M.

Conclusions

From these comparisons of aircraft structural metals, it is evident that PH 15-7 Mo offers the design engineer a number of important desirable characteristics. High elevated-temperature tensile strength is combined with excellent compressive yield strength and marked resistance to creep. Further, these mechanical properties are obtained with good fabricating qualities and corrosion resistance.

As of today, PH 15-7 Mo is beginning to interest aircraft manufacturers. Evaluation studies by leading aircraft manufacturers indicate considerable interest in PH 15-7 Mo as the principal material for construction of airplanes of the future. We look forward to its increased use.

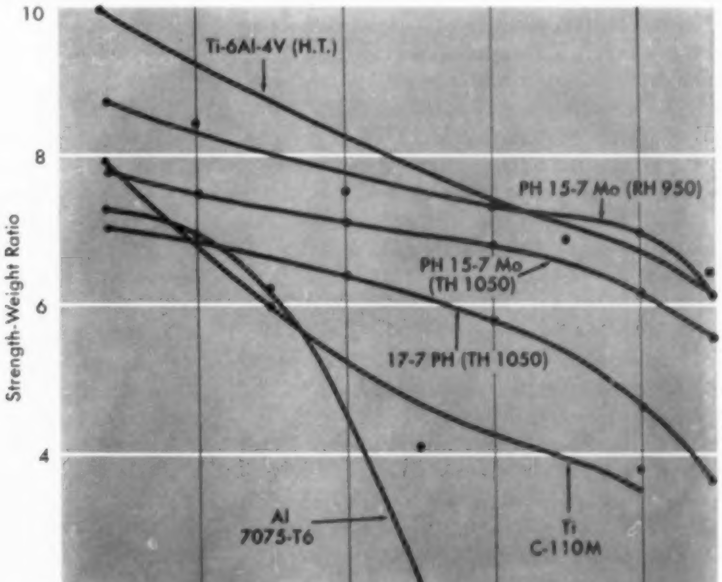
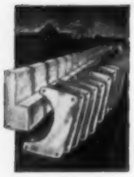


Fig. 7 – Compressive Strength Comparisons for Some Airframe Materials



Short Runs

New Look Comes to Steel

PARTS in the photo in Fig. 1 are a sample of what you can do with a new vinyl-coated steel just announced by U.S. Steel Corp. Supplied as sheets and coils in many surface textures, the precoated steel is made by a method developed by the company's researchers to cure and bond liquid vinyl plastisols to the metal. A key problem was to perfect a way to retain sharp definition of embossed patterns in the vinyl coatings during fabrication by deep drawing and bending.

Now that the precoated material is available in mill quantities at a cost only a little more than double the price of equivalent cold rolled steel, engineers are looking at the properties given below to see what they mean to sales appeal and durability of their products:

• Decorative Value – This comes from attractive colors and precise textures embossed in the coating.

• Mechanical and Chemical Toughness – This accrues from the well-known ability of vinyl to resist abrasion and scuffing and to withstand stain and corrosion from most common chemicals.

• Electrical Properties – Dielectric strength of the precoated steel is 750 v. per mil of coating. Thus, the average 10-mil coating on parts in Fig. 1 would resist 7500 v.

• Quality of Feel – Here we have a soft tactile quality associated with leather or tweed.

What Does It Cost? – Vinyl-coated steel is sold on a square foot basis. Typical price for 0.010-in. vinyl on 18-gage drawing quality steel, in quantities of 20,000 sq.ft. as a single color, would be 35¢ per sq.ft. – about 2½ times the price of steel alone. The same vinyl on a 24-gage sheet would be about 24¢ and on a 28-gage sheet the price would drop to 20¢.

Vinyl-coated steel is generally less expensive than stainless steel, anodized aluminum, wood, upholstery, porcelain enamel and solid plastics. However, it is more expensive than painted steel – the most widely used decorative material with which it competes. Fundamentally, the vinyl precoat has these basic advantages over paint: its textured appearance and warmth, and its resistance to scuffing, scratching and abrasion.

Variety of Colors and Textures – The vinyl is applied in controlled thicknesses of 0.008 to 0.020 in., as specified. So far as color is concerned, preference is to match whatever color the customer desires. Actually, almost any shade can be produced including the popular heavily metallized opalescent finishes.

Standard textures are available; however, any

texture can be produced which can be engraved on an embossing roll. In applications to date, the leather patterns have been most popular and are used in applications such as railroad car interiors, school cabinets, and business record storage cabinets.

Other products, particularly architectural and automotive applications, use a somewhat more exotic pattern. Texture is, of course, functional as well as decorative, and in uses where considerable abuse is anticipated, rougher textures are most suitable.

Fabrication — Vinyl-coated steel is supplied up to 52 in. wide, in coils or cut lengths, on either cold rolled, galvanized, or galvanized Paintbond steel. Both commercial quality for flat work and special killed steel for deep drawing are offered. A manufacturer of coolers uses 48-in. wide galvanized coils, while a producer of tape dispensers employs narrow coils which are slit from wide coils. No problems were encountered in either slitting or recoiling the strip.

Conventional shearing offers no problems. Sheets have been run through high-speed blanking operations without difficulty. With clean tools and adequate clearance, press brake forming is satisfactory. Extremely sharp corners may be produced if needed.

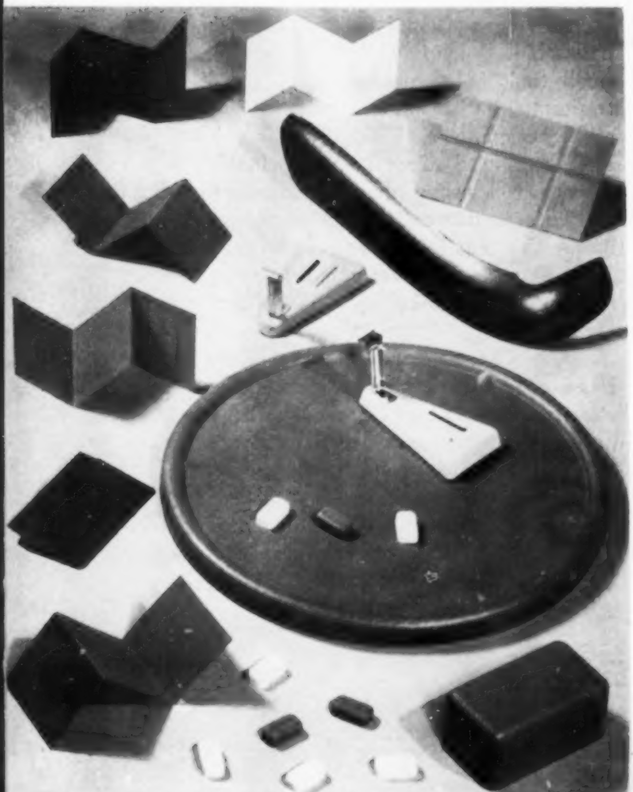
Automobile instrument panels and chair seats are now being deep drawn. In closed die operations, such as this, some attention must be given to die clearances. The vinyl layer is compressible to a degree. If die lubrication is required, water-soluble types are generally preferred because they may be easily washed off. In most instances, vinyl-coated steel can be worked on production dies already in use.

Assembly — Various types of indirect welding are used. Because vinyl is an insulator, current flow must be controlled from the back side. Several basic welding techniques are being applied: Graham stud weld, projection weld, capacitator discharge, spring-loaded electrode weld, and magnetic force weld.

Manufacturers are using other methods of joining, such as sheet metal screws for cabinets, pressure and heat bonding adhesives on doors, lock seaming on picnic cans and force-fit inserts on architectural panels.

Fig. 2 — These Products Are Being Produced From Vinyl-Coated Steel. Other applications are auto interiors, appliance cabinets, architectural products, railroad car and bus interiors, office fixtures and furniture

Fig. 1 — Fabrications Range From Flat Work to Deep Drawing in These Parts Made From Vinyl-Coated Steel



Cold Treatment for Better Properties

*By ROLLAND S. JAMISON**

Chilling of heat treated steel parts to −120° F. transforms retained austenite to martensite. Commercial refrigerating units are doing this today on a wide variety of parts. (J26q, W10g; ST)

A PHENOMENON familiar to all heat treaters is the hardening which occurs when a steel part is heated and quenched. This was a magic trick before the metallurgist came along; now it is known to be simply "the conversion of austenite to martensite by rapid cooling". Unfortunately, the reaction doesn't always go to completion, particularly in high-alloy steels and carburized parts. The unconverted material is called "retained austenite". Its presence means a lower hardness, and, being unstable, it can transform to untempered martensite after the part is tempered. It contributes to reduced ductility and undesired dimensional changes. Since this sort of part may fail rapidly in service, retained austenite is not wanted.

Getting rid of it is no simple matter, although cold treatment is known to have a beneficial effect. Quite often, parts with stringent requirements are packed in dry ice. Swiss watchmakers once stored parts at high altitudes for a year or more. Since both methods have obvious drawbacks, the trend nowadays is to refrigerate at −120° F. Transformation is accomplished in a matter of hours. Repeated cycles of freezing and tempering will eventually produce 100% transformation and, therefore, result in complete stabilization.

Types of Cooling Systems

Three types of chilling systems are available and can be adapted to many production requirements. The actual design of a system depends, of course, on the size of parts to be processed, the necessary rate of output, and the required temperature range. The illustrated systems, therefore, represent principles of operation and are not intended to blueprint any particular setup now in use.

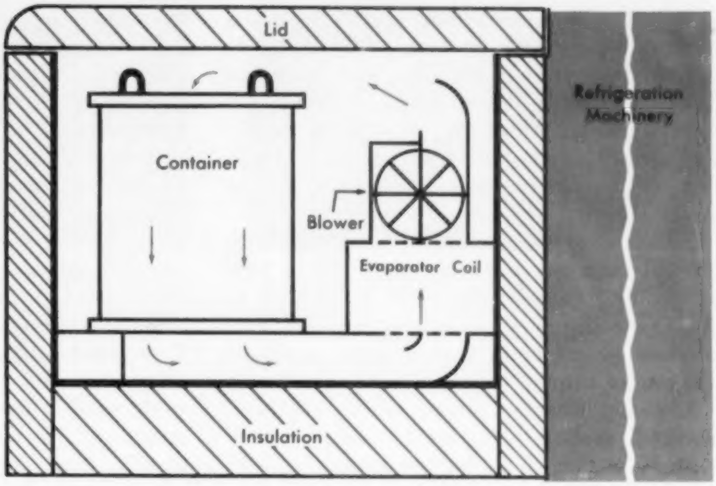
First shown in Fig. 1 is a system with a large chilling chamber, 10 to 250 cu. ft., containing a sheet metal basket or box to hold medium-sized parts from 2 to 8 in. in diameter. Mechanical convection within the chamber draws the air stream through the basket and passes the air directly over the refrigeration coils. This provides direct refrigeration of the parts. For larger items, the basket may be removed and the parts placed directly in the chamber; parts as large as a 10-ton mill roll can be processed.

In the next system, Fig. 2, a mesh basket holds small parts in a liquid convection fluid for quick, thorough chilling. This type of system is required for small components such as bearing balls, ball penpoints and a great variety of small tools. A propeller keeps the liquid in constant agitation to insure uniform contact with all basket contents. This propeller revolves in a baffled tube to effect uniform circulation and avoid mere swirling, thus maintaining maximum efficiency in convection of heat by way of the liquid. Various hydrocarbons (chloro and fluoro derivatives) are used for convection fluids; these include "Genetron-11" by Allied Chemical and Dye Co. and "Freon-11", a product of the "Kenetic" Chemicals Division of E. I. du Pont de Nemours & Co. Methylene chloride is also effective. Acetone and alcohols will do but must be used with caution since they are flammable. The preceding setups are batch-type systems.

Large-quantity rapid production (achieved by conveyers) is highly economical. The third system, Fig. 3, typifies several now in operation. The chilling chamber provides for four passes of

*Applications Engineer, Harris Refrigeration Co., Cambridge, Mass.

Fig. 1 — Batch-Type Refrigerator for Medium-Sized Parts. The blower circulates chilled air through the container and evaporator coil



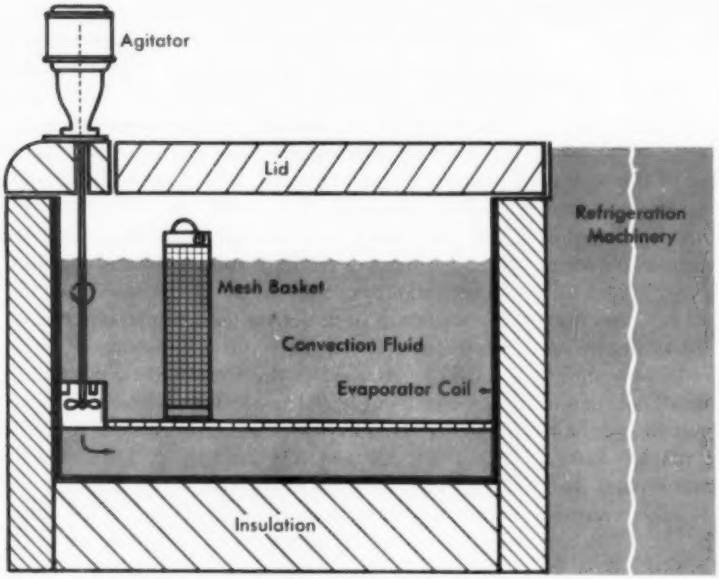


Fig 2 — Refrigerator for Small Parts. Since small parts pack compactly, a convection liquid must be used. The propeller circulates the liquid to provide uniform chilling of the basket contents.

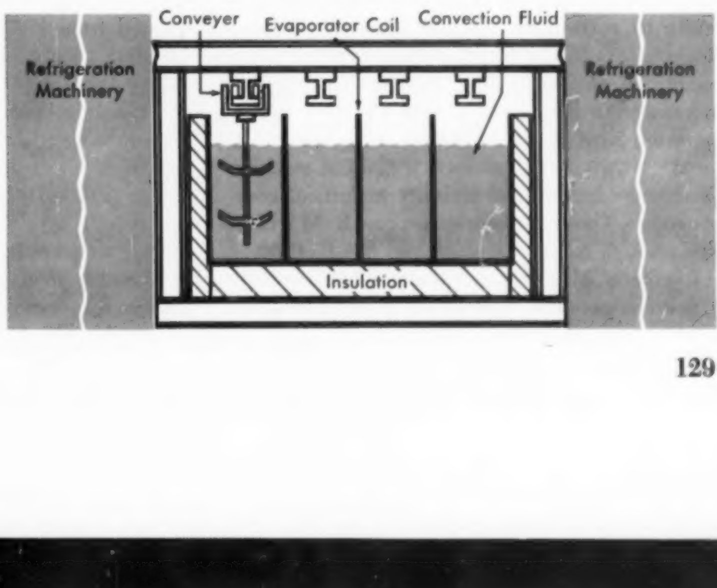


Fig. 3 — Conveyer System Handles Large Number of Parts

each part in the convection liquid. Liquid is used, rather than air, because it can be easily isolated from the outside air. Such a system can be tailored to individual jobs, limited only by the adaptability of the conveyer to handle the parts. Systems of this type now in use handle thousands of parts, each weighing 10 lb. or more, daily.

All three types of systems are built with thermal capacities to handle from 100 to 5000 lb. per hr. Theoretically, there is no limit to these systems, either in attaining practical temperature ranges or in size of parts processed and rate of output.

Assuming that the proper system has been installed, analysis will reveal a cost of only a small fraction of a cent per pound for cold treatment. This computation should, of course, include the original cost of the machine, amortization, water, electric power and maintenance. This should always represent a substantial saving over the use of dry ice for the same purpose.

Applications

Low-temperature treatment is already being used widely, with new applications being discovered almost every month. One of the widest present uses is for the stabilization of gages and precision parts. Many plants are applying it for high and low-temperature tests, calibration tests, shock tests on instruments, and cold bend testing of insulated wire. Another important application is for shrink-fitting; for example, an inner ball bearing race is cooled while the outer race is heated to facilitate loading. Tool manufacturers use the technique to control hardness of their product, and bearing manufacturers chill to control hardness of bearing parts and achieve dimensional stability. Nonferrous materials are also being cold treated.

Cold treatment for dimensional stability in toolsteels is used by the Hoover Co., North Canton, Ohio. Their high-carbon, high-chromium steels are sluggish in transformation from austenite to martensite. While hardness of only Rockwell C-58 to 60 is often revealed after tempering at 300 to 350° F., a chill treatment increases this by several points. Another manufacturer, New York Air Brake Co., has relied for three years on a production chilling machine to achieve dimensional stability in critical components. These toolsteels are used: M 2 HSS, 9310, S.A.E. 52100, Deward and S.A.E. 6150.

Raytheon Mfg. Co. uses a chilling machine to test components. Resistance to thermal shock is a critical requirement for the magnetic components, transformers and inductors in military electronic equipment. The cold shock temperature cycling test breaks susceptible parts. Satisfaction with the first unit led the company to install 20 additional machines for environmental testing of components.

Bearings that will operate at temperatures which may vary from −65 to +150° F. require complete dimensional stability. Miniature Precision Bearings, Inc., depends on a chilling machine to minimize molecular rearrangement in Type 440-C stainless steel and S.A.E. 52100. They also chill various tool and high speed steels, used in tools and gages. Their machine maintains temperature within 5° F. – a uniformity more than adequate.

Fenwal, Inc., uses cold treatment in three departments – engineering, quality control, and production. In the engineering laboratory a chilling machine has been employed for five years in environmental tests of temperature control and alarm units and systems. Their quality control laboratory uses a chilling machine for low-temperature ambient tests, calibration tests, and shock tests on low-temperature range thermistors, thermocouples, and liquid-filled controllers operating from −100 to +200° F. In the production department, a chilling machine has maintained −120° F. for two years without interruption or shutdown. It is used to relieve stresses in materials used in manufacturing thermo-switch controls.

Chilling is used in the treatment of precipitation hardening stainless steels – Armco's 17-7 PH and PH 15-7 Mo (see p. 121) and Allegheny Ludlum's AM 350 and AM 355 (see p. 116). After cold treatment, the steel retains its strength at skin temperatures exceeding 600° F. In the June 1958 issue of *Metal Progress*, an article on "PH Stainless for Hot Airframes" cites the experience of Chance Vought Aircraft in designing a critical bulkhead where titanium could not be used because of space restrictions. The part is preformed from 17-7 PH, annealed at 1750° F. for 10 min., then cooled to −100° F. and held for 8 hr. Aging at 950° F. for 60 min. follows. The refrigeration and tempering method produces less distortion, reduces chance of error in shop practices and is less costly.

The process of chilling has been in general use for only a few years, and every month it is finding new applications. Every plant that heat treats alloy steels may well consider the economies and qualities cold treatment can give.

Personal Mention

Thomas C. Fetherston

THOMAS C. FETHERSTON, assistant director of public relations for Union Carbide Corp., New York, has retired to follow up one of his major interests – public education. Over the past 25 years, he has acquired quite a reputation in this field – he has served on countless committees, written a good many articles and talked on various educational topics – and he feels that the time has now come to devote the major part of his time to this increasingly important and expanding area. His attentions will be directed primarily toward writing – editors and publishers have been pressing him for more and more material.

His interest in public education has not been limited to local school affairs; he is well-known in the state and nationally. He is serving on the New York State Regents Council on Educational Television, the State Commission on Retirement and the Comptroller's Committee on School District Finance. In Oceanside, Long Island, where he lived until recently with his family, he served on the Board of Education for more than 20 years; elected president in 1937, he was re-elected every successive year until 1958. He helped to organize and was first president of the South Nassau School Boards Assoc.

Since 1951 he has been a director of the New York State School Boards Assoc., one of the oldest and largest organizations of lay school officials in the country and a powerful and active force in that state and the nation; he has been president of that organization for the past three years.

Despite such active plans for his "retirement", Fetherston intends to find more time to direct toward his 252-acre farm in Maryland, looking out over Chesapeake Bay, where he now resides with his family (and a substantial herd of Herefords and Aberdeen-Angus cattle which he has been raising for the past 15 years).

His career with Union Carbide began in 1919 when, after his discharge from the field artillery, he joined the Linde Co. division. He moved to the New York office several years later where he helped to organize Linde's technical publicity department, which later became the public relations department for the corporation. When he retired last year, he was assistant director of public relations.

His society memberships include both technical and educational organizations, such as the Manufacturing Chemists Assoc. and the National Teachers Assoc. His association with A.S.M. includes a stint as a member of the first *Metal Progress* Advisory Board.

Harry Major, Jr., resigned as research professor at the University of Alabama to accept a post as head of mechanical engineering at Seattle University where research on thermal cycling is being conducted under the sponsorship of the Office of Ordnance and Research.

Duane C. Carlson, who graduated from the University of Michigan in June with a B.S.E. in metallurgical engineering and chemical engineering, is now employed in the metallurgical laboratory at the Belle Works of E. I. du Pont de Nemours & Co., Inc., near Charleston, W. Va.

H. T. Cousins, for 22 years district sales manager in the Detroit area for National Machinery Co. of Tiffin, Ohio, has been assigned to Nüremburg, West Germany, as director of overseas sales operations for the company and will be associated with its German affiliate J. G. Kayser Co.

Zolly C. Van Schwartz has been made technical consultant for the C. A. Norgren Co., Englewood, Colo. and its subsidiary Norgren-Stemac, Inc. He was director of engineering standards for Baldwin-Lima-Hamilton Corp. for 12 years prior to joining Norgren.

Robert White has been appointed manager of alloy steel sales for the Sheffield Div., Armco Steel Corp., Houston, Tex. Mr. White has been special representative for alloy sales for Sheffield in Houston for two years.

George J. Foss, a 25-year member of A.S.M., has taken a position with Anchor Hocking Glass Corp., Lancaster, Ohio, as director of package engineering and research laboratories. Until accepting this new post, he was affiliated with the consulting management firm Spencer R. Stuart and Associates, Chicago.

Earl T. Hayes has been named chief metallurgist for the U. S. Bureau of Mines, Washington, D.C. Before his transfer to Washington in 1956, Dr. Hayes worked at the College Park, Md., Salt Lake City, Utah, and Albany, Ore., stations and was closely associated with the Bureau's development of both titanium and zirconium.

Richard F. Harvey was recently registered to practice before the U. S. Patent Office.

Robert J. Perry has been assigned to the Pittsburgh territory of Surface Combustion Corp., Toledo, as sales engineer.

Gordon McMillin has been elected president of Canadian Steel Wheel Ltd. Mr. McMillin is also president of Canadian Steel Foundries Ltd.

S. F. Reiter has been named a lecturer in the department of metallurgy at Yale University. Dr. Reiter, technical manager of the Rome Fastener Corp., New Haven, Conn., will teach a course in metals technology.

William C. McCue, formerly chief metallurgist of the Steel Improvement & Forge Co., Cleveland, has been advanced to manufacturing manager of the company's East 64th St. plant in Cleveland.

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Personals . . .

Stephan A. Montanaro has resigned as president of City Testing and Research Laboratories, Inc., to accept an appointment as president of Academy Testing Laboratories, Inc., New York.

G. Boyd Berrett has resigned from his position as forging specialist at the General Electric Co. Thomson Laboratory in Lynn, Mass. He is now chief metallurgist at McInnes Steel Co., Corry, Pa.

James R. Patterson is currently vice-president of Downey Steel Treating Co., Inc., Downey, Calif.

Erling Klafstad has been elected president of Crosby Valve and Gage Co., Wrentham, Mass. For the past eight years, he was assistant director of engineering at Manning, Maxwell and Moore, Inc., Stratford, Conn.

Mark Irwin has moved to the new U.S. Bureau of Mines laboratory at Fort Snelling in St. Paul, Minn.

John Y. H. Ahn is currently a production specialist in the U. S. Army assigned to the Republic of South Korea.

Alexander Squire was recently appointed manager of the newly formed materials department at the Westinghouse Electric Corp.'s Bettis Atomic Power Div. in Pittsburgh. He formerly was manager of the Bettis SFR project that developed the nuclear power plants for the submarines Skate, Sargo, Swordfish and Seadragon.

Richard C. Wiley, chairman of the welding department at California State Polytechnic College, San Luis Obispo, Calif., since 1946, will head a new welding and metallurgical engineering department. The new department is being organized to offer the bachelor of science degree in metallurgical engineering, and the new curriculum will be offered in September.

James H. Dodge, formerly Detroit district manager of Latrobe Steel Co., Latrobe, Pa., has been transferred to the home office as sales manager of the specialty steels division.

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Second, only Carlson produces these Armco grades in the heavier plate thicknesses. For applications where high strength at high temperatures and ease of fabrication are important, get plates in these grades from Carlson. We will be glad to work with you on specific applications.

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Personals . . .

Edward J. Wellauer has been promoted to director, research and development, in the engineering division of the Falk Corp., Milwaukee, Wis. Affiliated with the company since 1933, he served most recently as assistant chief engineer, materials and research.

J. G. Pearce has retired as director of the British Cast Iron Research Assoc., Alvechurch, Birmingham, England.

William J. Phillips has resigned as vice-president and general manager of Crawford Steel Foundry Co., Bucyrus, Ohio, and is presently traveling in New Zealand and Australia, visiting steel foundries and related industries.

Robert R. Miller, president of Precision Metalsmiths, Inc., Cleveland, was elected president of the Investment Casting Institute at the sixth annual meeting in New York.

F. L. Moffet and **A. P. Terrile** have been appointed to new positions with the metallurgical division of Crucible Steel Co. of America, Pittsburgh. Mr. Moffet, formerly chief metallurgist at the company's Park Works in Pittsburgh, has been named material and process engineer (conversion and treatment). Mr. Terrile, a Crucible customer contact metallurgist, has been appointed field service metallurgist.

Earle C. Smith, chief metallurgist and director of research for Republic Steel Corp., Cleveland, has been elected a foreign honorary member of the Verein Deutscher Eisenhüttenleute, receiving the award personally in Dusseldorf on Nov. 7, 1958.

Howes Bodfish, sales technical advisor for the Aluminum Co. of America's Philadelphia district, has retired following 31 years with Alcoa. He joined Alcoa as a sales trainee in the Philadelphia district sales office and three years later became a resident salesman in Baltimore, devoting a good deal of time to developing the use of aluminum in aircraft. In 1945 he was named manager of the Baltimore sales office and two years ago was assigned his current position.

Personals . . .

William S. Clouser ⊕ has been added to the faculty of the University of Wisconsin's college of engineering as assistant professor of engineering mechanics. Dr. Clouser received his doctorate in engineering from Wisconsin last August.

Robert D. Everett ⊕ has been named general superintendent of the Melrose Park, Ill., works of National Malleable and Steel Castings Co., Cleveland. Before this transfer, he was finishing department superintendent in the company's Sharon, Pa., works.

Floyd R. Anderson ⊕, administrative assistant of the Denver division of Gardner-Denver Co., Quincy, Ill., has been named chief metallurgist of the firm, supervising metallurgical operations of all divisions, both domestic and foreign.

Robert L. Felt ⊕ has been appointed product metallurgical engineer in Crucible Steel Co. of America's metallurgical division in Pittsburgh. Mr. Felt joined Crucible in 1951 as a staff metallurgist at the company's Midland, Pa., works and was promoted to assistant chief metallurgist four years later.

Robert E. Keith ⊕, metallurgist at the General Electric Research Laboratory, Schenectady, N. Y., has been appointed to the liaison scientists staff in the area of metallurgy and ceramics. Liaison scientists are responsible for maintaining a flow of information between the research laboratory and the company's operating components throughout the country.

Richard S. Mateer ⊕ has joined the faculty of the University of Kentucky as head of the department of mining and metallurgical engineering.

Clifton J. Huffman ⊕ has been appointed technical director of the R. D. Werner Co., Inc., of Greenville, Pa. He was formerly associated with the Dow Chemical Co. in the capacity of research and development engineer and extrusion plant metallurgist, and more recently was plant technical superintendent and extrusion technical specialist for Kaiser Aluminum & Chemical Corp.

Personals . . .

Edward C. Sullivan, Jr. ⊕, after receiving a bachelor of science degree in metallurgy from Massachusetts Institute of Technology in June, joined Bethlehem Steel Co. After completing the company's training course, he has been assigned to the metallurgical department of the Bethlehem Sparrows Point, Md., plant.

Walter R. Johnson ⊕, a recent recipient of a bachelor of science degree in metallurgy from Massachusetts Institute of Technology, is currently a metallurgist for the missile systems division of Raytheon Mfg. Co. at Bedford, Mass.

Harrison C. Pulsifer ⊕, formerly senior metallurgist at Firestone Steel Products, Wyandotte, Mich., and Firestone Tire and Rubber Co., Akron, Ohio, now heads the new welding facilities at the Detroit plant of the Budd Co.

Ralph P. Edwards ⊕ is presently employed as a metallurgist in the openhearth department of the Youngstown Sheet and Tube Co. in Youngstown, Ohio.

Ralph G. Sultan ⊕ is on extended leave of absence from Linde Air Products Co., a division of Union Carbide Canada Ltd., to attend Harvard Business School.

William Bailey ⊕, after graduating from Carnegie Institute of Technology with a bachelor of science degree in metallurgical engineering, joined the Airesearch Mfg. Co., Los Angeles, as a metallurgist in the materials and process laboratory.

Clyde Williams ⊕, president of Clyde Williams and Co., Columbus, Ohio, and formerly president of Battelle Memorial Institute, was awarded the James Douglas Gold Medal of the American Institute of Mining, Metallurgical, and Petroleum Engineers at the national meeting of the A.I.M.E. last month. The award cited Dr. Williams "for outstanding contributions in nonferrous metallurgy, particularly through stimulating research and interest in the basic metallurgy and the use of both the common and less common metals".

Metals Engineering Digest

. . . Interpretative Reports of World-Wide Developments

Materials Problems of Rocket Engines

Digest of "Materials Problems Encountered in Liquid Propellant Rocket Engines", by Donald E. Roda. Paper presented at Society of Automotive Engineers Annual Meeting, Detroit, Jan. 12, 1959.

COVERING the service range −300 to +5000° F., materials for rocket engines which use liquid propellants present many difficult problems. Fortunately, it is possible to regeneratively cool parts of the engine which reach temperatures of 1500° F. and higher.

Differential thermal expansion is a problem in parts such as bolts which hold the volute of the casting for the liquid oxygen pump together and the vanes in place. High-strength bolts are required, yet the bolt diameter is limited by vane thickness. The greater contraction of the aluminum alloy casting shrinks it away from the bolts (which are some 3 in. long), leaving them loose. Good low-temperature strength and toughness are required along with a high thermal coefficient of expansion in these bolt materials. Alloy A-286, heat treated to an ultimate strength level of 145,000 psi. (coefficient of expansion is 8.3 compared to 10.5 for aluminum), is better than heat treated Inconel "X" with an ultimate strength of 175,000 psi. and a coefficient of 5.7, if an appreciable length of material is used.

Low-Temperature Mechanical Properties – These present a related problem. Type 410 and 440 C stainless steels are of interest because of their corrosion resistance and high strength in the heat treated condition. Parts without sharp corners or stress-raisers, which are not subject to impact loads, such as the shaft for the gate of the liquid oxygen valve, have been successfully made from these materials. The martensitic steels in the heat treated condition are subject to a low-temperature transition giving brittle failure. Mechanical properties at −320° F. (liquid nitrogen testing temperature) had not been determined, and tests were made. Figure 1 shows that there is a large increase in ultimate and yield strength in going from room temperature (white area) to the low test temperature, −320° F., (black area) for 400 series stainless in the heat treated condition. Also, elongation is less at low temperature; at −320° F. it's about 7% for 410 and 2% for 440 C. (*Cont. on p. 144*)

Fig. 1 – Mechanical Properties at Room Temperature and at −320° F. for Some 400 Series Stainless Steels in Heat Treated Condition

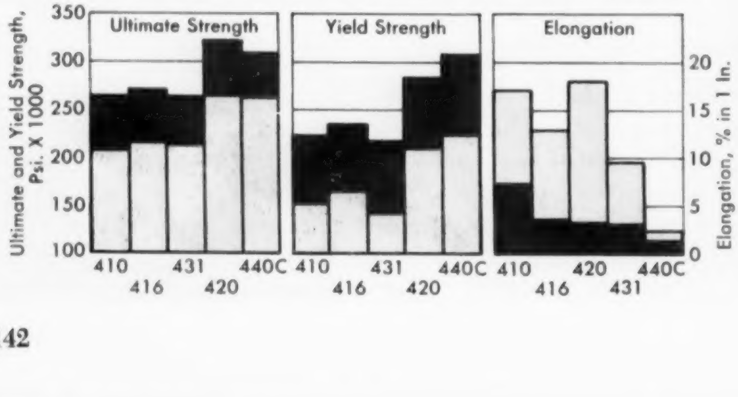

Fig. 2 – Failure of Gear Tooth Due to Fatigue After 1700 Sec. Test in Rocket Engine

Rocket Engines . . .

Gear Failure – Fatigue of gear teeth is an example of the type of problem which is solved by failure analyses. Figure 2 shows an intermediate gear with two teeth missing after 1700 sec. of test operation. The fractured tooth area on close examination revealed typical bench marks of a fatigue failure.

Gears are made of S.A.E. 9310 steel to AMS Specification 6260 E, carburized to a final case depth of 0.025 to 0.035 in. and hardened to Rockwell C-60 minimum. The failure analysis showed heat treated structure which was unsatisfactory, nonuniform case depth and inaccurate tooth contour. Gear failures have been completely eliminated by tightening quality standards and inspection requirements.

Castings – Aluminum castings make up a large part of the turbopump and are used for other parts of the rocket engine. Originally castings from Alloy 356-T 6 were used for oxidizer and fuel volutes, impeller and gear box. Increased power requirements and upgrading of turbopumps and engines put more load on the pump parts and castings. Strength of the castings was progressively increased with sodium-modified 356-T 6, high-purity 355-T 6 and 356-T 6, and finally through the use of a new alloy developed by North American Aviation, known as Tens-50 and having 50,000 psi ultimate tensile strength. (Information concerning it may be obtained from Navan Products, Inc., El Segundo, Calif.)

Compatibility – This accounts for some of the more recent material requirements. With the introduction of certain high-energy and storable propellants, problems of corrosion and compatibility of metals and plastics with these liquids have arisen. A storable oxidizer can be described as one which is liquid near or at ambient temperatures and pressures. For example, nitrogen tetroxide has a freezing point of +13° F., a boiling point of +68° F., and is a powerful oxidizer. In the presence of water it forms both nitric and nitrous acid. Figure 3 shows the operating mechanism of the main valve for the oxidizer after less than 2 hr. of operation with nitrogen tetroxide. The cadmium plate on

World's biggest dump truck—made with USS "T-1" Steel—hauls 165-ton loads at 35 mph. Western Contracting Corp. conceived the truck, had it designed by Charles W. Jones, engineering firm of Los Angeles. Fabricators of box and frame: Eaton Metal Products Corp., Omaha.

World's biggest truck made 25% lighter with USS "T-1" Steel

Your first impulse is to dive for the ditch when you see this mastodon of trucks roaring down the haul road at Oahe Dam near Pierre, South Dakota. But if you're an equipment builder, you will wonder how they got the tremendous strength necessary without adding too much dead weight.

That was the problem faced by the Western Contracting Corporation of Sioux City, Iowa when they decided to build the biggest possible dump truck. It is an 18-wheel, 750-hp semi-trailer that is currently hauling a payload of 110 yards or 165 tons. The truck is 55 feet long, 16 feet wide and 14 feet high.

25% lighter. To get this high capacity with the least weight, they built the box and frame of USS "T-1" Constructional Alloy Steel. "T-1" Steel had a minimum yield strength of 90,000 psi but is now available at 100,000 psi. Western estimated it saved 12½ tons in dead weight or 25% of the trailer's weight.

Good fabricating properties. Because USS "T-1" Steel can be readily formed and welded, all members could be built up from plates. Reinforcing for the box was formed into channels through which exhaust gases are piped to keep the load from freezing in cold weather.

High resistance to impact abrasion. Dumping a 165-ton load in a few seconds causes terrific abrasion. "T-1" Steel is noted for its ability to take this kind of punishment, and it gives much longer service than ordinary steel.

In addition to 100,000 psi "T-1" Steel, we produce three brands of USS High Strength Steel in the 50,000 psi Yield Point range—MAN-TEN, COR-TEN and TRI-TEN. Each has its own characteristics that make it ideal for certain applications in construction and mining equipment. Find out how these steels can reduce weight, increase strength, and lower your operating costs. Address United States Steel, Room 2801, 525 William Penn Place, Pittsburgh 30, Pennsylvania.

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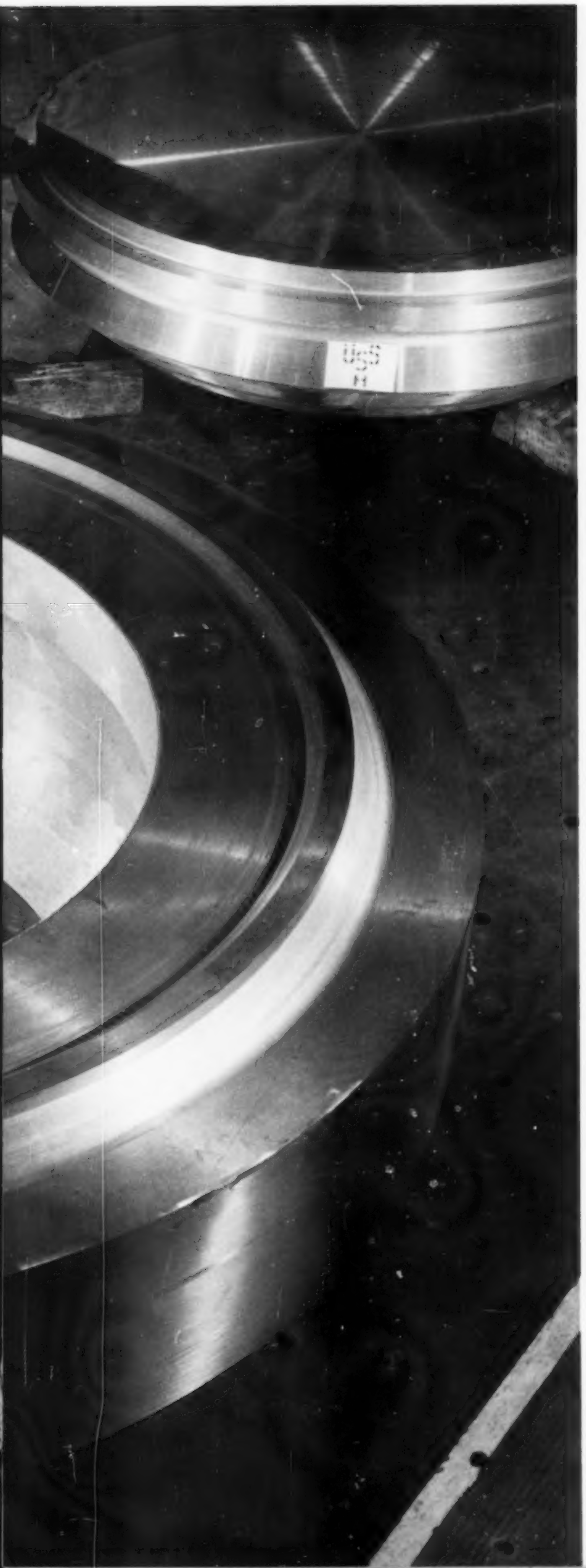

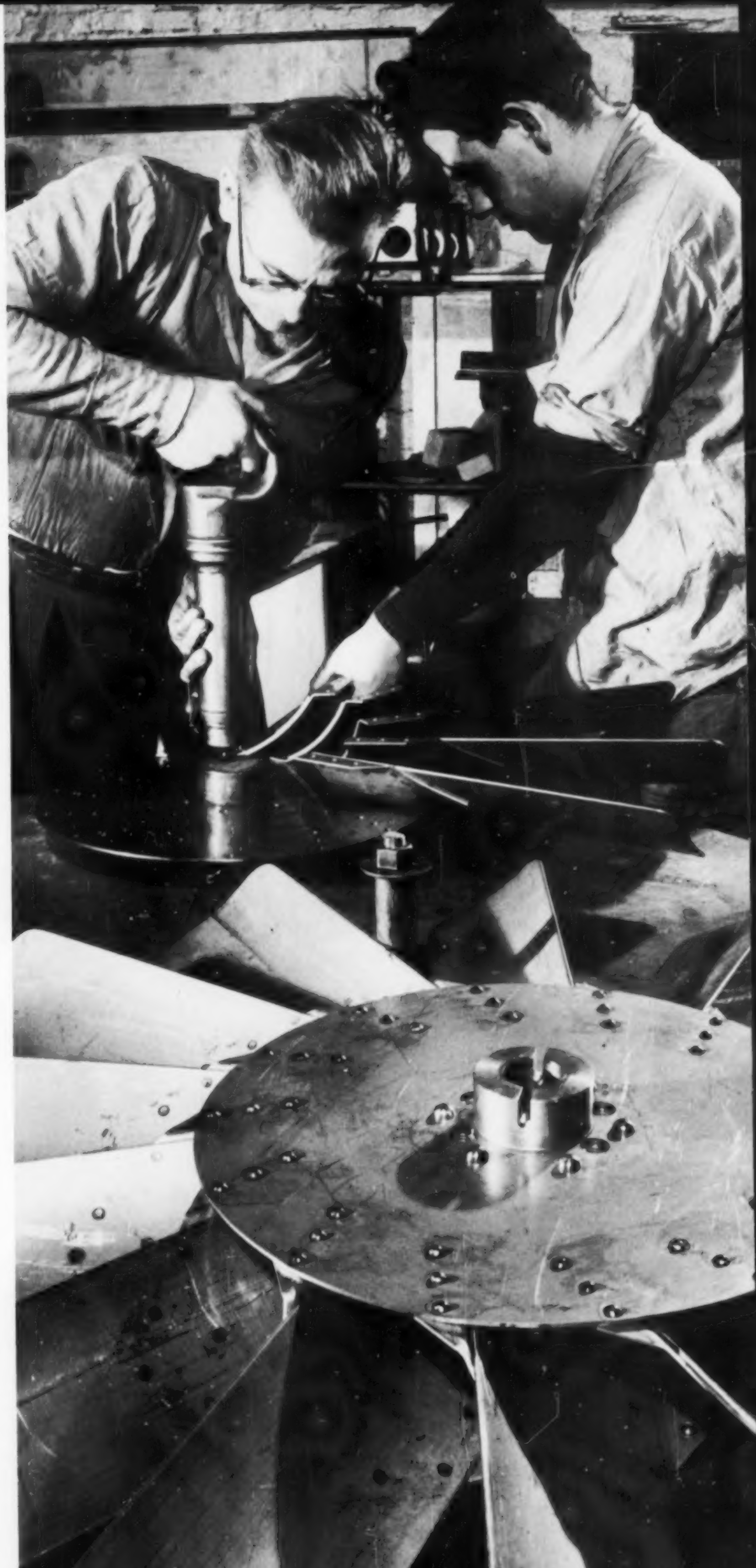


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Rocket Engines . . .

the steel parts has been almost completely removed and the steel is heavily rusted. Inside the valve, the nitrogen tetroxide removed the anodized coating from the 75 ST aluminum gate, softened the Kel-F lip seal so that part of it broke away, and rusted the lock ring for the lip seal retainer.

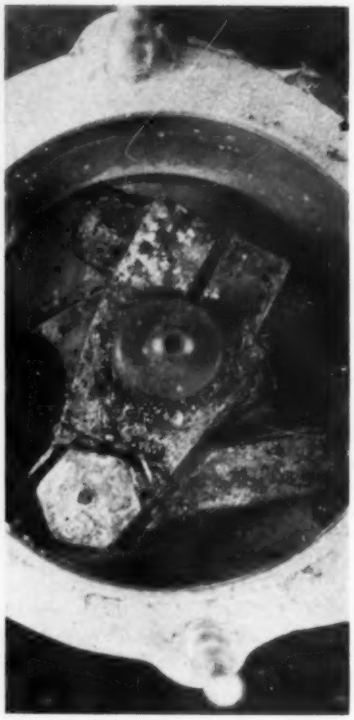

Fig. 3 – Corrosion of 4130 Steel Parts (Cadmium Plated) Which Comprise the Operating Mechanism for Main Oxidizer Valve. This valve was removed from a rocket engine after 2¾ hr. exposure to a storable propellant, nitrogen tetroxide

Problems of compatibility vary to a great extent with the parts. The material and service requirements for a tank are considerably different from those of shaft or valve. One might have continuous exposure to both vapors and liquids while the other might have intermittent exposure to either liquid or gas. Compatibilty of materials with new propellants will present many future materials problems in rocket engines.

Fabrication – Welding and brazing are used to a great extent,

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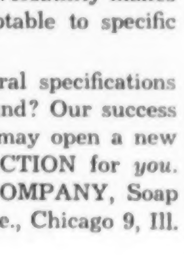

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Lean, fine, dry lubricant for low carbon bright and cold heading wires.

FLEXAL MCA

Metallic stearate base. Medium veri-grind compound.

FLEXAL MCF

Metallic stearate base, rich fine mesh drawing compound.

FLEXAL CS

A pure calcium stearate, 58°—60° C. titer, 325 mesh (max.).

*Flexals can be either soluble or insoluble in water for solvents, depending upon need.

Rocket Engines . . .

Considerable development work is often required for a particular part. An example is the welding of cast Stellite 21 blades to a 16-25-6 forging for turbine wheels. So many blades are required that there is not enough room for the fir tree or mechanical attachment.

Short-time elevated-temperature properties of metals and nonmetals interest the rocket engine builders while longer time properties interest most other industries.

Lubrication – Extremely clean hydraulic oil is required for satisfactory operation of servo valve mechanisms which provide the tremendous multiplication of power in small units to transform electrical impulses (or electronic signals) into forces which control the rocket engine. A program to develop standards for the amount and size of dirt particles in hydraulic oil is in progress.

The characteristics of oils for lubricating and cooling the gear box is important both at ambient pressure and at high altitudes, where components must operate in almost a complete vacuum unless they are pressurized. Oil meeting specification MIL-T-6068, used for lubrication, foams at high altitude unless an antifoam agent is added or the gear box is pressurized. Dry film lubricants, such as the molybdenum disulfide coatings, are used on some components. Tests in an altitude chamber show that a high vacuum or lack of moisture and oxygen at high altitudes greatly increases the coefficient of friction. A.G.G.

Ultrasonic Testing of Aluminum

Digest of "Effect of Internal Flaws on the Fatigue Strength of Aluminum Alloy Rolled Plate and Forgings", by J. L. Waisman, C. S. Yen, L. L. Soffa and P. W. Kloeris, Jr. Paper presented at the meeting of the Society for Nondestructive Testing, Cleveland, October 1958.

THOUGH ultrasonic techniques have come a long way since their introduction nine years ago, aircraft manufacturers still have difficulty in deciding when to reject material. Logically, the best approach is to

Ultrasonic Testing . . .

reject material defects large enough to affect the mechanical properties. This can be done for defects that lower the *static* properties; however, for the dynamic properties, such as fatigue strength, the problem is not so simple. Since much smaller defects affect the fatigue strength, and there is a lack of dependable data, no accurate acceptance limits have been established. To fill this gap, engineers at Douglas Aircraft Co. and Northrop Aircraft Co. have performed a large amount of research, some of which is reported in this paper.

Theory

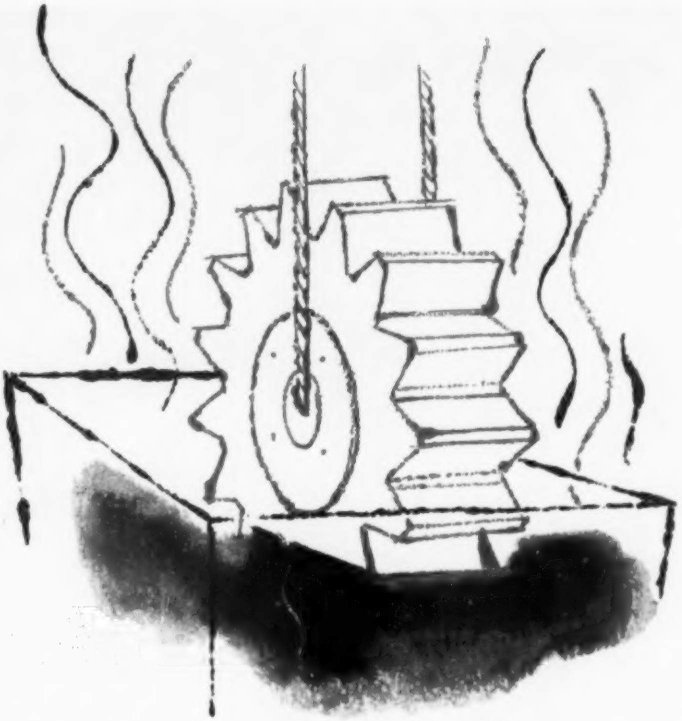
In evaluating flat pancake-shaped defects (the most common type in metal stock), we must consider the direction of applied stress, and the defect size and its location. The greatest effect on fatigue strength occurs when stress is applied perpendicular to the defect (this defect, of course, acts to concentrate the stress). For a circular defect shaped like a plate, it is assumed that stress concentration depends on the *ratio* of the defect-to-surface distance to the defect diameter (C/D), and the *ratio* of the specimen thickness to the defect diameter (W/D). This information is derived by mathematical analysis of a simulated symmetrical defect; it can be written: $S=59+14\ C/D+0.6\ W/D$, where "S" is percent of "sound" material fatigue strength.

Experimental Work

Material known to contain flaws was selected, and these flaws were located by ultrasonic inspection. After cutting the material into blocks, fatigue specimens were machined so that each one contained a flaw. In addition, three blocks without flaws (but adjacent to blocks with flaws) were cut and machined for comparison specimens. Short transverse, long transverse, and longitudinal specimens (see Fig. 1) were machined from 7075-T 6 aluminum plate, 2½ in. thick. Hand-forged billets (7079-T 6) and die forgings (7079-T 6 and 2014-T 6) also provided fatigue tests.

There was also an attempt to correlate the actual diameter of the

(*Continued on p.* 154)



New "Comapro" project cuts machining time up to 30% . . .

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Only five months under way, the Cooperative Machining Project known as "Comapro" has already developed unusual time-saving and cost-cutting machining practices, using Gulfcut Cutting Oils.

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This is right in line with the over-all objective of "Comapro"—to develop more efficient ways to cut the cost-per-part figures in a wide variety of machining jobs, particularly in mass production. Findings will be made available to the entire metalworking industry.

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Ultrasonic Testing . . .

defects with the size indicated by the ultrasonic signal. The grain was set so that a 3/64-in. diameter test block yielded a signal 2 in. high. Figure 2 shows that defects giving signals of this height varied from 3/64 to about 15/64 in. diameter. Also, defects yielding signals 1¼ in. high actually ranged from 1/16 to 13/64 in. diameter. With these variable results, it was necessary to relate fatigue data with actual defect sizes, not sizes indicated by ultrasonic signals.

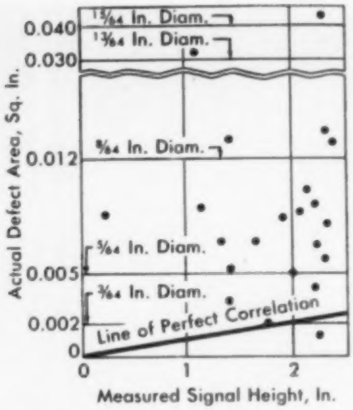

Fig. 2 – Comparison of Ultrasonic Signal Height With Defect Area. Scope was adjusted so that 3/64-in test hole yielded signal height of 2 in.

Analysis of Data

When all of the data were combined and analyzed, it was first noted that a large amount of scatter occurred if the largest diagonal or diameter of defect (D) and minimum distance from center of defect to surface (C) were compared separately with the fatigue strength. However, when these values were combined with the specimen diameters (W), in the ratios C/D and W/D, a good degree of correlation was noted. By treating the data in accordance with the formula quoted earlier ($S=59+14C/D+0.6W/D$), the graph shown in Fig. 3 is obtained.

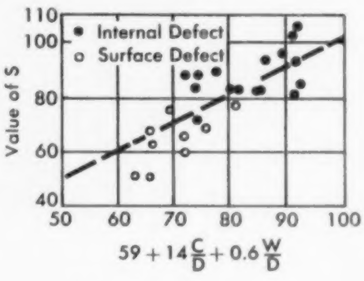

Fig. 3 – Effect of Variables on Fatigue Strength

The authors suggest establishment of acceptance policies on the basis of these data as follows:

1. The edge of the defect should not be within 1.5 defect diameters of any surface.

2. The defect diameter should not be more than 1/10 of the lowest section thickness.

3. The defect diameter should not exceed ⅛ in. (*Cont. on* p. 156)

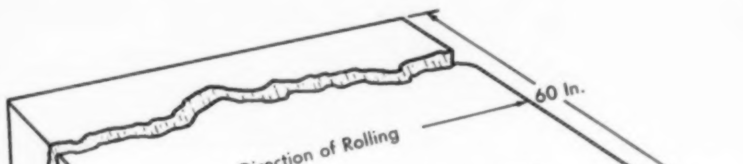

Fig. 1 – Orientation of Test Specimens

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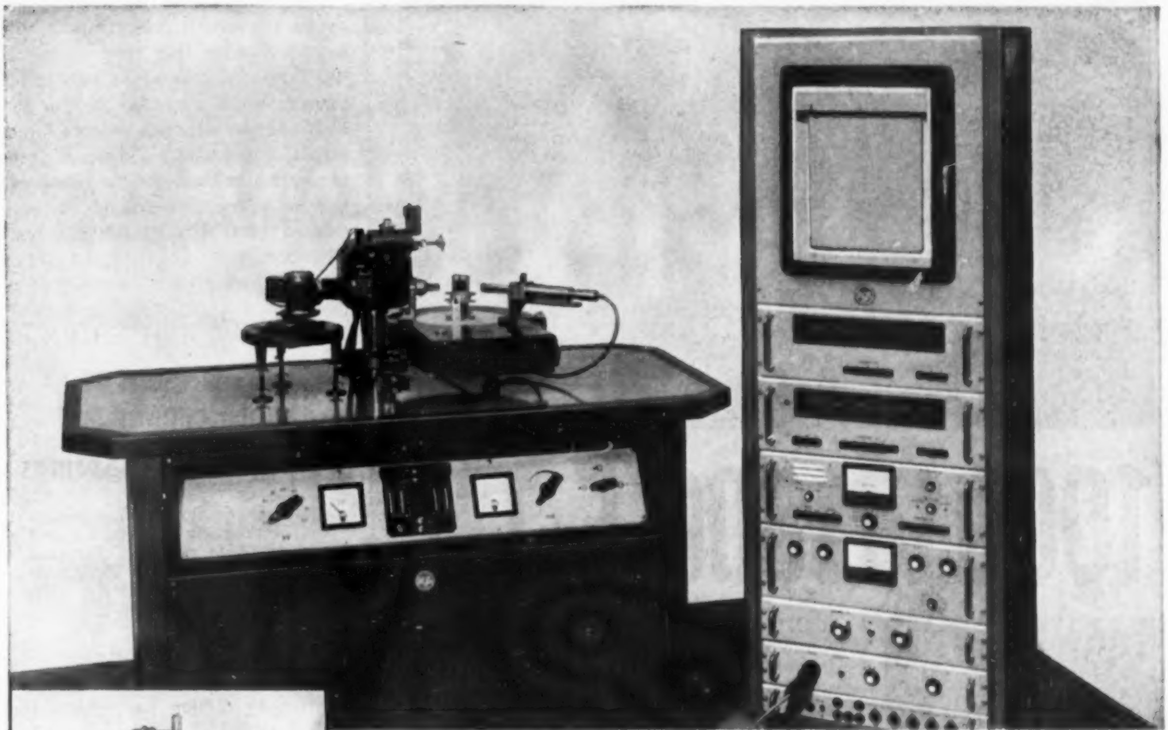

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Ultrasonic Testing . . .

They emphasize that these rules apply to actual defect sizes, and suggest further that sizes indicated by ultrasonic indications be tripled for aluminum alloys to account for discrepancies between observed and actual defect sizes. These suggestions are admittedly on the conservative side, but they should be considered until ultrasonic techniques have been refined to the point where there is better correlation between indicated and actual defect sizes.

C.R.W.

Shot-Peening and Prestressing of Springs

Digest of "Special Techniques for Increasing Strength and Fatigue Life of Steel Stressed in Torsion", by N. E. Hendrickson, *ASTM Bulletin*, No. 224, September 1957, p. 40-42.

THIS PAPER discusses the benefits derived from shot-peening and prestressing torsion bar springs for track-type vehicles. Prestressing is defined by the author as "the application of a controlled overload to produce permanent set in members in which the strains vary across the section". It is considered to be especially valuable where the loads are of considerable magnitude and in only one direction.

The torsion bar springs under discussion are about 59 in. long and 1 11/16 in. in body diameter with the ends being appropriately upset and splined for anchorage. They are made of Magnaflux-quality A 8660 Cr-Ni-Mo steel and are hardened in an electric resistance heater, with high-frequency booster coils at the upset ends. After heating to a temperature of 1550 to 1650° F., the red-hot bar is transferred to a special quenching machine that spins the bar between rollers as it cools in quenching oil at 125° F. After 2 to 3 min. in the spin quench, the bar is ejected and manually transferred to an oil tank at 250° F. Here the transformation to martensite is completed. Subsequent tempering is at 800° F. in a circulating hot-air furnace, giving a tempered martensitic structure of Rockwell C-48 throughout the section.

(*Continued on p. 160*)

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Springs . . .

Following hardening and straightening, the body of the bar is shot-peened and then preset. The presetting operation is performed in a special hydraulic-powered twisting machine. The specification for the bar under study calls for a 75° twisting angle, which is about 50% beyond the elastic limit. Repeated twisting to 75° and unloading is employed. The set after the first twisting ranges between 15 and 20°; the second twisting usually gives another 2° set, while the next twist may give only ½° further set. This twisting or presetting is repeated until no further set occurs, which usually takes from three to six twisting cycles.

In the manufacturing program, any finished torsion bar may be picked at random for a fatigue test up to 50,000 cycles from 5° initial to 49° final twist. The 49° twist is the torsional elastic limit of the steel before presetting. During the fatigue test, the test bar is removed after 500, 1000, 5000, 10,000, 25,000 and 50,000 cycles and the permanent set recorded in each case. During the past four years, the author's company has run fatigue tests on 46 bars as routine checks on production from 27 heats of steel. Of these bars, 38 met the ordnance requirement of 5° maximum set after 50,000 cycles. The remaining eight bars were rejected because of insufficient hardenability.

To demonstrate that shot-peening and presetting are responsible for the extraordinary fatigue life of these torsion bars, fatigue tests were also run on bars in which these special operations had been partially or wholly omitted. Tests were run through the usual range of 5° initial to 49° final twist, and in each case the machine was adjusted after appreciable set had occurred to restore the full 44° maximum travel. In each case, the fatigue life was considerably inferior when the operations of shot-peening followed by presetting were not performed. In fact, it was estimated that shot-peening and presetting make it possible for 40 lb. of steel in these torsion bar springs to do a job that would otherwise require almost twice as much material.

HANS CONRAD

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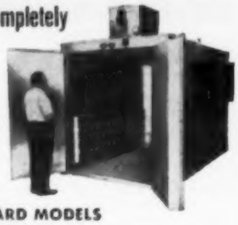

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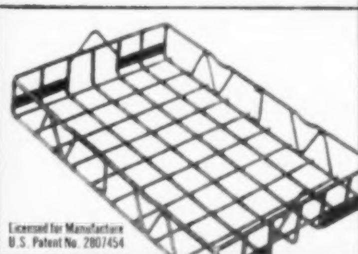

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Processing Variables and M-252 Properties

Digest of "The Influence of Processing Variables on the Properties of M-252", by R. G. Stuligross, J. Luchok and D. S. Chambers. Paper presented at the A.I.M.E. meeting, New York, Feb. 20, 1958.

FINISH ROLLING TEMPERATURES, solution temperatures, and boron content influence the grain size and mechanical properties of M-252. For the experiments needed to determine their effects more accurately, three 250-lb. ingots (boron content – less than 0.0002, 0.0015 and 0.0060%, respectively) were forged, mill cogged, and rolled to ⅝-in. diameter bars. Finishing temperatures ranged from 1750 to 1925° F. Stress-rupture tests at 1500° F. and 40,000 psi., and hot tensile tests at 1350° F., were used for this study.

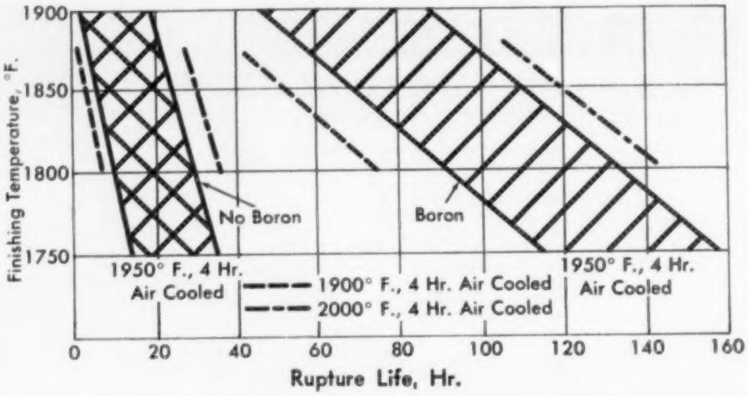
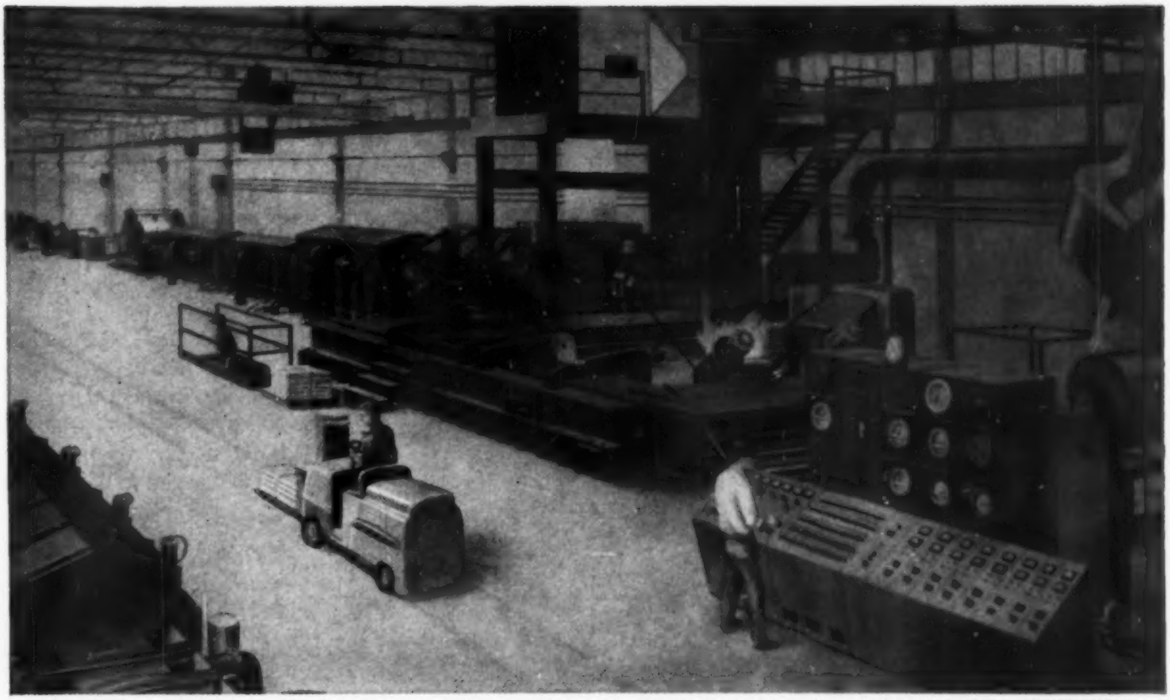


Fig. 1 – Finishing Temperature Versus Stress-Rupture Life for Indicated Solution Treatments. Tests were made at 1500° F. under a 40,000 psi. load

Grain Size

The as-rolled grain size varied from A.S.T.M. 9-10 at the higher finishing temperatures to a much finer grain size at the lower finishing temperatures. Hardness also rose from Rockwell C-31 to 34 (indicating higher stresses) as the temperature was lowered. Recrystallization occurred at the higher temperatures, while elongated grains were prevalent in material finished below 1780° F. Boron has no observable influence on either the as-rolled grain size or the as-rolled hardness. When solution treated at 1950° F., the grain size varies inversely with the finish rolling temperatures.

Rupture strength is increased by higher solution temperatures and the presence of boron. Since both finishing temperatures and solution temperatures can influence grain size and rupture life, it appears that grain size can be used as an indicator to determine property trends. Figure 1 shows that rupture life varies inversely with the finish rolling temperature. It may then be said that the rupture life varies with the grain size, the larger grained material having the greatest life. At 1500° F. failure is intergranular; it follows therefore that large grains should result in high rupture life (less grain



The above is a partial view of the two continuous galvanizing lines at the Martins Ferry, Ohio, plant of WHEELING STEEL CORPORATION. Both lines use AJAX 60 cycle induction galvanizing furnaces and zinc premelt furnaces. The main galvanizing furnace shown holds 175 tons of zinc, is rated 2000 kw, and produces over 40 tons per hour at speeds in excess of 300 feet per minute. These continuous galvanizing lines produce WHEELING's patented SOFTITE sheet.

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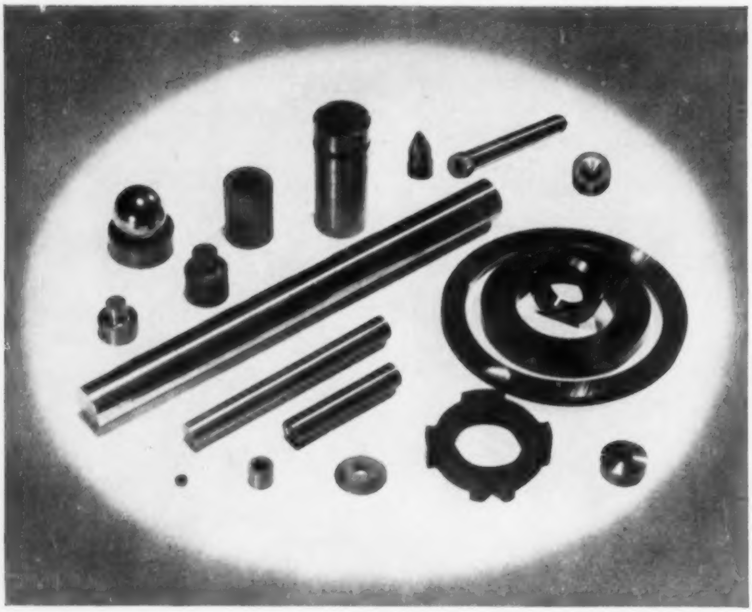

Kennametal can be supplied as standard rectangular blanks, discs, rods, tubes, flats, balls, rings . . . and can be extruded, pressed, machined or ground . . . to precise tolerances for specific requirements.

M-252 Properties . . .

boundary material present). However, grain size can be used as an indicator only if the same boron levels are being compared.

Rupture ductility increases with the finish rolling temperature, and is decreased by higher solution temperatures. The reverse occurs, however, for the 1350° F. tensile ductility. This is lowered by raising the finish rolling temperature (Fig. 2). Higher solution temperatures tend to increase tensile ductility, while lower solution temperatures tend to decrease it.

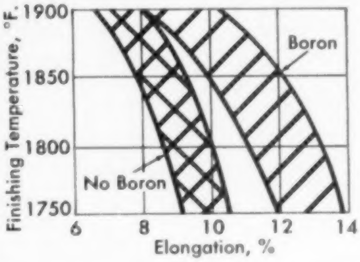

Fig. 2 – Finishing Temperature Versus Hot (1350° F.) Tensile Elongation

The fracture in the short-time tensile test at 1350° F. is transgranular; and since the boron effect is primarily associated with grain boundaries, it does not have the same effect on the tensile ductility as it does on the stress-rupture ductility. Boron does improve in textile ductility slightly, possibly due to its deoxidation effect.

Discussion

Rupture life and ductility will be the same for comparable grain size, provided that the solution treating temperature ranges from 1950 to 2025° F. Carbide banding could be reduced by finishing hot and solution treating above the normal treating temperature. High heating and working temperatures effectively disperse carbides.

Practically, finish rolling temperatures are limited to between 1925 and 1730° F. Finishing above 1925° F. requires extremely high starting temperatures in the range where incipient melting is apt to occur. Severe transverse cracking results when finishing temperatures are below 1730° F. (*Cont. on p. 174*)

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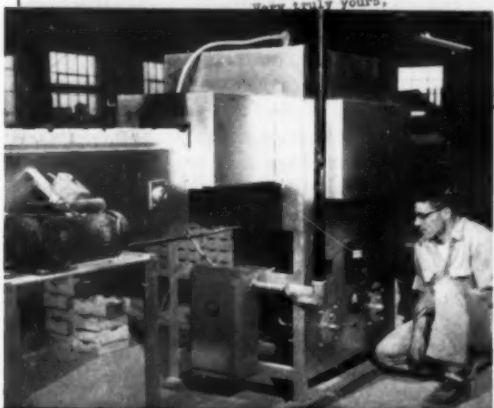

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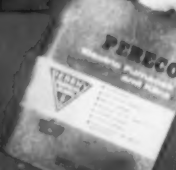

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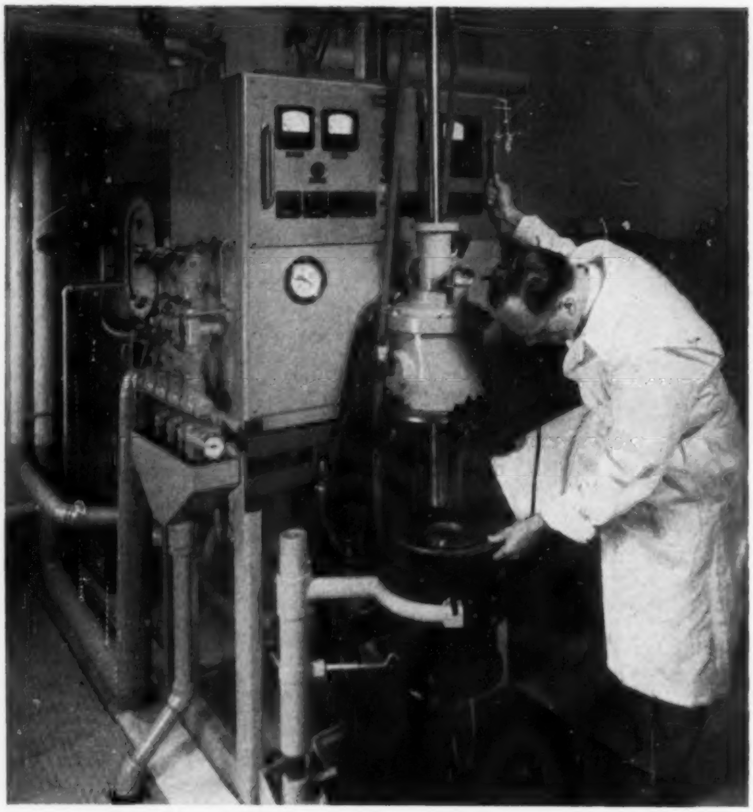

M-252 Properties . . .

For a given boron level, elevated temperature properties can be controlled by a combination of the finishing temperature and solution treating temperatures. The specification of solution treating temperatures for the final product makes it mandatory that finishing temperatures be accurately controlled to arrive at the specified levels of mechanical properties. This, in effect, limits what can be done to control carbide banding in this alloy.

C.R.W.

Impending Shortage in Blast Furnace Coke

Digest of "Emerging Patterns in Coking Coal Supply", by Hubert E. Risser, Illinois State Geological Survey. Paper presented before Chicago Section A.I.M.E., Feb. 5, 1958.

GENERAL STATEMENTS about the vast American supplies of coal should be interpreted to mean coals of all sorts. When attention is turned to the major coking coals of eastern Kentucky and southern West Virginia – from which comes the supplies for pig iron production in Illinois and Indiana – it appears that shortages will appear within 20 years. This is graphically shown in the curves on p. 176. The upswinging curves marked "requirements" are based on an increase in demand of 2% per year, the over-all rate of increase in pig iron production in the United States since 1900. The curves for production are composites for developed and existing seams (including reserves) and are of the bell shape which represents production from any mine or district – it gradually rises toward a high, levels off on a hood summit, and then declines. If the known reserves in these states should be doubled – which is highly unlikely – the curve of production would be moved upward and to the right a distance equal to about 40 years; that is to say the shortage would only be postponed a couple of generations.

The author suggests several forehanded actions to meet the impending and nearby shortage. First, intensify existing research on the

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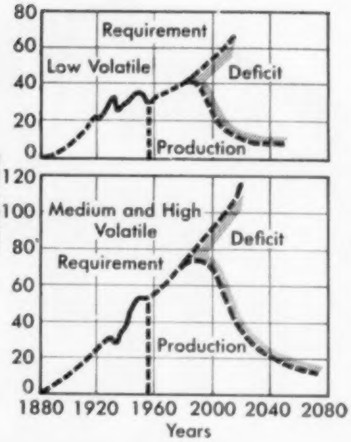
Blast Furnace Coke . . .

blending of local noncoking coals with the good Appalachian coals – in other words, use larger percentages of high-volatile to conserve the scarcer low-volatile coals. Second, tailor the coke quality to the real rather than the fancied needs of the blast furnace. Third, restrict the use of such valuable coals to coke manufacture; at present about half of that mined is used for other purposes. Fourth, increase the recovery at the mine – only 50 to 70% of the coal in the seam reaches the coke oven.

In the view of this reviewer, while all these expedients will be useful, they will only postpone the evil day when the American iron and steel industry will either have to import coking coal from some at present unknown foreign deposits, or turn to the potentialities of low blast furnaces and electric iron. E.E.T.



Projected Future Requirement and Production of Major Coking Coals of Eastern Kentucky and Southern West Virginia

Shrinkage Defects in Iron Castings

Digest of "Shrinkage Defects in K-Bar Test Castings", by J. Gittus, *Journal of Research and Development*, British Cast Iron Research Assoc., Vol. 6, February 1957, p. 456-483.

Shrinkage defects in iron castings present the investigator with a particularly elusive problem. In determining the influence of a number of variable factors, it is customary to vary each separately with the values of the remaining factors held constant. Unfortunately, the cumulative effect on shrinkage of slight fluctuations in factors whose values are presumably held constant may outweigh the effect of deliberate variations in the factor being specifically studied.

Broadly speaking there are two ways of overcoming this difficulty:

1. All of the factors may be varied simultaneously and the average effect of each factor on shrinkage determined statistically.

2. Each factor may be varied separately and the experiment repeated to increase the precision with which their individual effects are defined.

In the present investigation, the first method proved suitable for the study of the general effects of analysis and melting conditions on the volume of shrinkage defects in test castings. The second approach was

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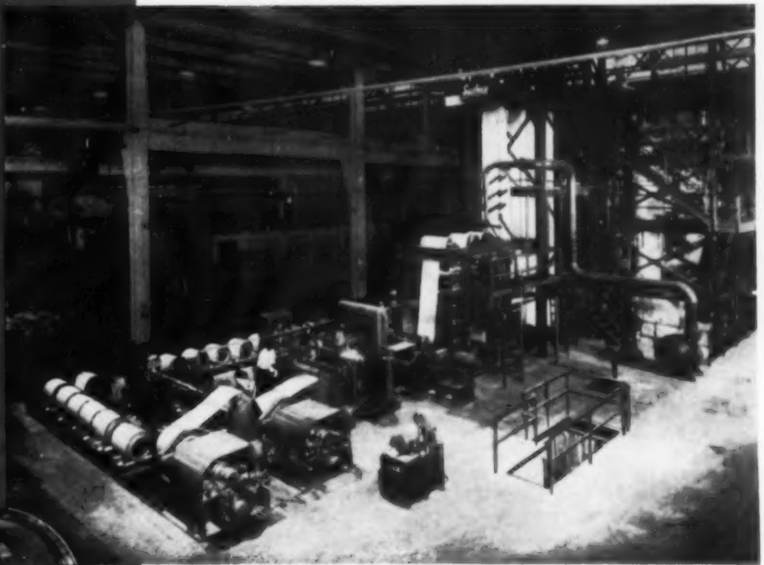

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Shrinkage Defects . . .

used to investigate the effects of inoculation, furnace conditions, analysis, and mold properties on the type of shrinkage defects exhibited by test castings.

Twenty-nine melts were made in an oil-fired crucible furnace, each comprising about 60 lb. of a suitable pig iron, and ferro-alloys. From each melt were cast ten green sand molded K-bar castings that are particularly prone to contain shrinkage defects. The volume of the shrinkage defect was estimated by filling it with a measured quantity of dry sand. The defects took the form of surface depressions adjacent to the hottest part of the casting. None of the castings contained internal porosity.

Effects of Variables on Shrinkage Volume

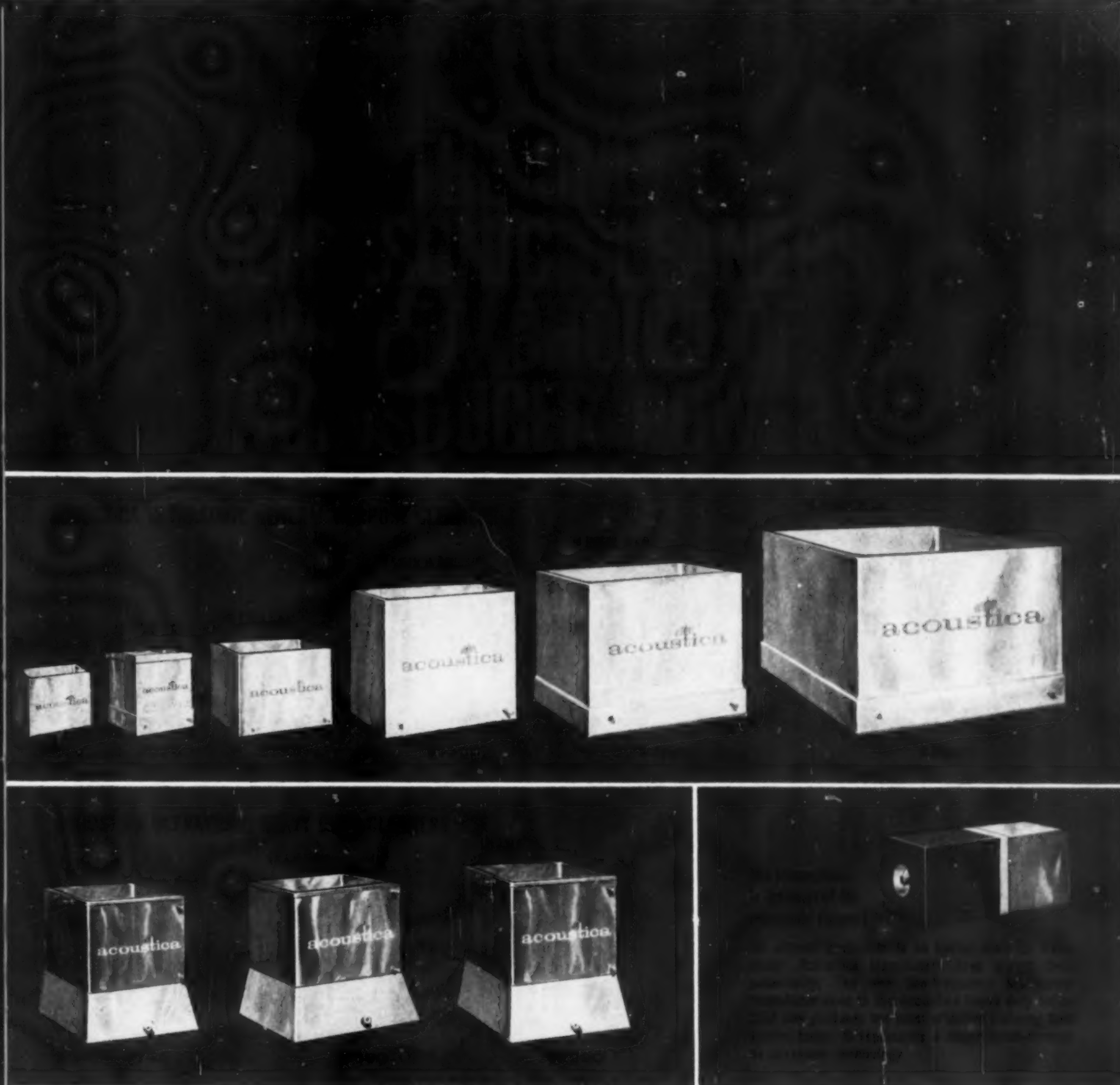
Variable	Regression Coefficients	Effect of Observed Change	Effect of 10% Change
Max. furnace temperature	+0.001	+0.18 cc.	+0.15 cc.
Time interval charge-tap	+0.0037	+0.52	+0.06
Av. pouring temperature	−0.0065	−1.00	−0.91
Carbon content	−1.3	−0.44	−0.37
Silicon content	+0.43	+0.33	+0.07
Manganese content	−0.79	−0.21	−0.05
Sulphur content	−0.73	−0.042	−0.007
Phosphorus content	−0.037	−0.009	−0.002
Shatter index of sand	+0.029	+0.41	+0.22

Preliminary tests of the relationship between nine individual variables and the shrinkage volume were made. As a result of these preliminary tests, several variables were eliminated as being of little importance. The individual and combined effects of the remaining variables on the shrinkage volume were then determined by regression analysis, details of which are described in an appendix. In this way, the individual effects which each of the nine variables would have had on shrinkage, if the other eight variables had been maintained absolutely constant, were revealed.

Values of regression coefficients were obtained for each of the nine variables. Each of these values indicated the change in shrinkage volume brought about by a change of one unit in the specified variables. These have been used to indicate the change in shrinkage volume brought about by the maximum change in each of the variables, that is, by a change from the lowest to the highest value studied. These effects were compared as shown in the table.

The following specific conclusions were made by the author.

1. Green sand molded K-bars produced under conditions approximating those which will occur in a commercial foundry contained surface defects whose average volume was generally reduced by (*a*) lowering the maximum temperature obtained by the furnace, (*b*) reducing the melting time, (*c*) raising the pouring temperature, (*d*) lowering the silicon content, (*e*) raising the carbon, manganese, sulphur, or phosphorus content, and (*f*) lowering the shatter index of the sand. Since alterations in the level of these



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Shrinkage Defects . . .

variables can cause trouble other than shrinkage defects, the practical application of these observations should be a matter of some caution.

2. Internal porosity was most pronounced in K-bars of high-phosphorus and low-carbon content, especially when the metal had been inoculated by a late addition of ferrosilicon. Superheating the metal in the furnace reduced porosity in the resulting castings.

3. Carbon dioxide process molds produced castings containing less shrinkage and porosity than similar castings made in green sand molds.

4. Shrinkage and porosity in K-bars of various compositions were not influenced by wide variations in the oxygen content of the metal.

W. W. Austin

Slip Casting of Metal Powders

Digest of "Slip Casting of Metal Powders", by Henry H. Hausner. Paper presented at the 14th Annual Meeting of the Metal Powder Assoc., Philadelphia, April 23, 1958.

Slip casting is a process well known to the ceramic industry for the production of ware of large size or complicated shape. Clay or talc powder is mixed with water into a creamy "slip" or "slurry" of proper viscosity and a little deflocculant added to prevent setting. This slip is then poured into an appropriate plaster of paris mold which absorbs most of the water, leaving behind a coherent casting which has sufficient strength for safe handling and firing in the kiln.

In the experiments described in this paper, the powder was Type 316 stainless steel made by Bower Bearing Co., characterized by uniformly spherical shape and high density of the particles. It was carefully sized and mixed with water and fractional percentages of deflocculants (or binders) trade named "Marex" and "Superloid," which are ammonium salts of alginic acid. Viscosity and pH of the suspension were also varied according to a definite program. These two variables are entirely new to the powder metal-

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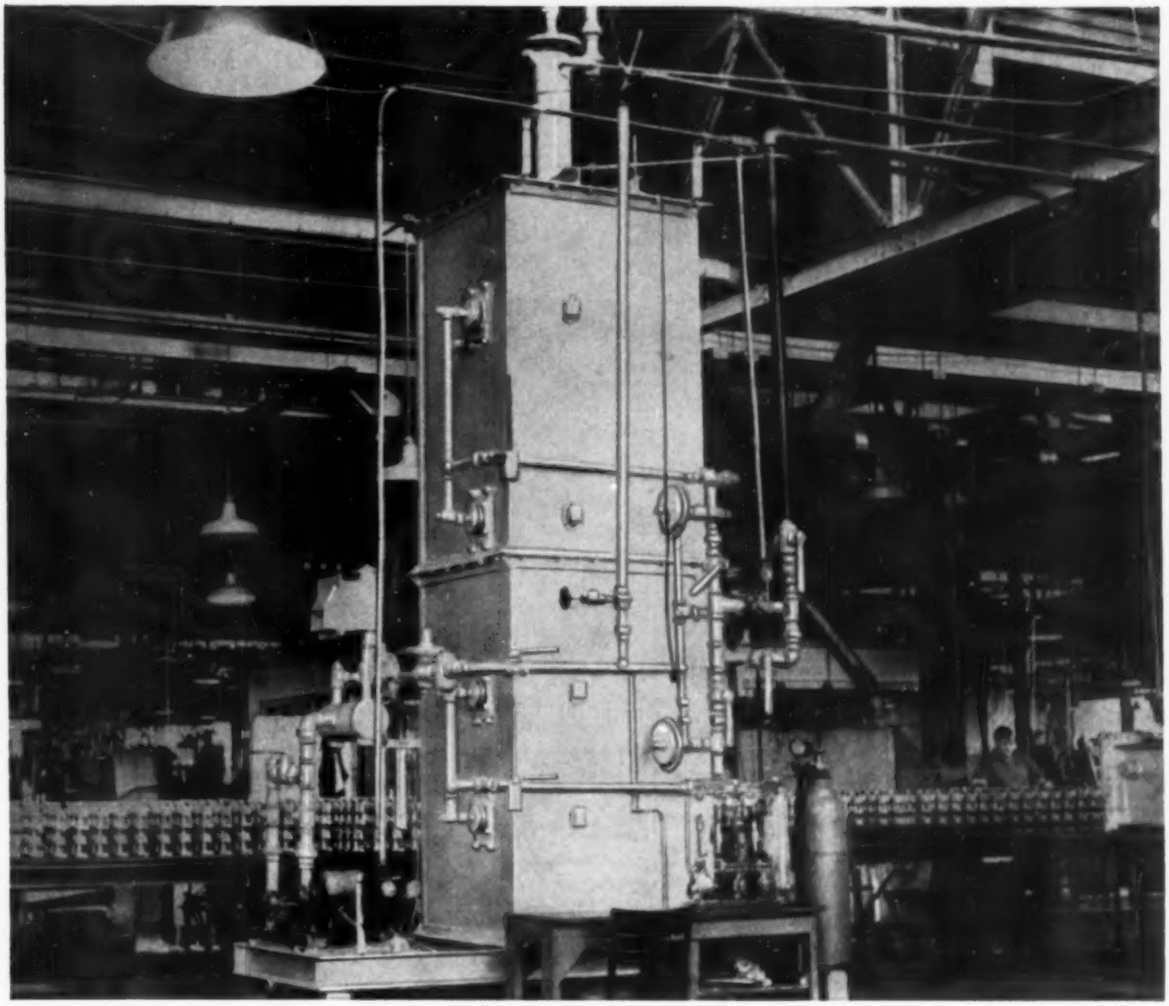

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Slip Castings . . .

lurgist, yet both are of utmost importance and apparently must be adjusted to optimum values according to the particle size, particle shape, and nature of the solid or mixture of solid particles.

Mixtures of Type 316 and UO_2 have been slip cast successfully. The pH of the deflocculant solution is considerably less than that of the slip, indicating that there is some chemical reaction between stainless steel and the alginate, and the author intimates that the latter may be an effective binder. At any rate, enough of it (perhaps 0.4%) is necessary for a "green" or "as-cast" strength high enough for safe handling – on the order of 1200 psi. The pH was adjusted up or down to the desired figure by adding drop-by-drop concentrated NaOH or HNO_3 respectively.

There is a much larger shrinkage in slip castings during firing than there is in pressure compacts. However, shrinkage is remarkably uniform in any given dimension. On the other hand, pressure gradients in ordinary compacts strongly influence the dimensional changes in sintering. For example, a $2 \times 12 \times 0.20$-in. flat plate (slip cast) became a sintered object $1.92 \times 11.18 \times 0.15$ in. in dimension, thus shrinking 8.7% longitudinally, 12.3% in width and 17.7% in thickness, but *without* warpage. Its density was 95% of theoretical, its tensile strength 70,000 psi., and its elongation 40% in 2 in.

It should be mentioned that, for conventional pressure compacting of a plate of these dimensions, a 1200-ton press and an expensive hardened steel die would be necessary, whereas for slip casting such a plate, no press and a plaster of paris mold costing approximately $30 were used. It is possible to produce inexpensively one or ten plates of this type, and also to produce in this way hundreds of plates. This illustrates some of the advantages which slip casting has to offer.

The slip casting process has been used to produce various shapes from stainless steel – complicated shapes such as turbine blades and especially hollow turbine blades with a certain porosity for cooling purposes – as well as flat plates of relatively large dimensions.

From the above description it will be evident that in slip casting the powder particles keep their original shape, the contacts are point-to-point and touch at ambient temperatures. In pressure compacting, on the other hand, the particles are deformed plastically, touch on larger contact areas, and develop considerable heat in deformation and rubbing against each other.

Action during sintering is considerably different because in a slip casting the touching particles possess their original crystalline defects at their surfaces and within their body (predominantly point defects), the apparent density is low and the voids mostly equiaxed pores. In the pressure compact a bond already exists at many places where the particles have rubbed together, the pressure has formed new defects in the crystal (predominantly linear

Slip Castings . . .

defects), the green density is considerably higher and the voids are elongated in directions perpendicular to the pressure.

Consequently in the pressure compacts new crystal nuclei are formed and recrystallization takes place during sintering. In the slip castings practically no nucleation occurs and a continuous grain growth takes place in the mass powder particles, first within the individual particles, and, when diffusion bonding starts, grains may grow from one particle to another. In slip cast and sintered material with a porosity of about 5%, outlines of the original powder particles are evident.

Slip casting of metal powders and of cermet powder mixtures actually offers a new avenue in powder metallurgy. Slip casting should not, and never will, replace the conventional pressure-compacting of certain parts, but rather permits an extension of metal powder applications to large and complicated shapes, and, therefore, for an economic small-scale production for which the conventional powder metallurgy methods are not applicable.

Slip casting is definitely not just an interesting laboratory method, but offers good aspects for production, and will probably contribute to a considerable growth of the powder metallurgy industry. The data on slip casting stainless presented in this paper are to be taken only as examples. Slip casting of several metals, such as tungsten and molybdenum, is under development, and the results are promising. E.E.T.

Atomic Hazards During Fires

Digest of "Radioactive Materials and Industrial Fire Protection", address presented by F. R. Farmer, United Kingdom Atomic Energy Authority, to Industrial Fire Officers' Conference at Leamington, England, May 15, 1958.

THE NUMBER of uses of radioactive isotopes in medicine, industry and research is growing at an exponential rate. They range in toxicity from very high to very slight; they range in potency from a very low level (on


LINDBERG

Atomic Hazards . . .

the order of 100 millicuries) to a high level (say 10 curies). They normally are kept in sealed containers and stored in shielded places. The storage area should be within concrete walls and therefore virtually fireproof, and common sense should indicate that there should be no nearby accumulation of combustible materials such as paints or lubricants.

At present the widest industrial use is for X-ray examination and inspection, for which cobalt-60, iridium 192, and caesium 137 are available – all fortunately of moderate toxicity. However, the fire marshal as well as the plant's fire brigade should know where the normal storage is situated and be informed immediately of the equipment's location if it is in use somewhere else and a fire breaks out in the vicinity.

If the source emits low level radiation, no particular precautions need be taken by the firefighters. Subsequent salvage work should, however, be done under careful supervision.

If it is a source of medium level – say 1 to 5 curies–firefighters should don normal protective clothing. Debris from the fire should not be disturbed, however, until a survey of the premises is made by competent personnel and adequate equipment.

If the source emits a high level of radiation, firemen with their protective clothing and breathing apparatus should attempt to stay upwind. Even so, they should assume that their clothing is contaminated and particular care be taken when removing and later handling it – which should be done only in a clean area. It is highly unlikely that persons would be damaged downwind from such a fire as long as they are outside the smoke cloud which in itself would constitute a strong irritant.

Aftermath – People should keep clear of the burned area. A competent employee should identify the position and condition of the radioactive material. An expert (who should be known to the fire department and who should have been on call) should examine the situation within hours, determine whether the material has been dispersed and if so where, and he alone should direct the clearance and decontamination of the site. E. E. T.

CLEANING AND ANNEALING LINES

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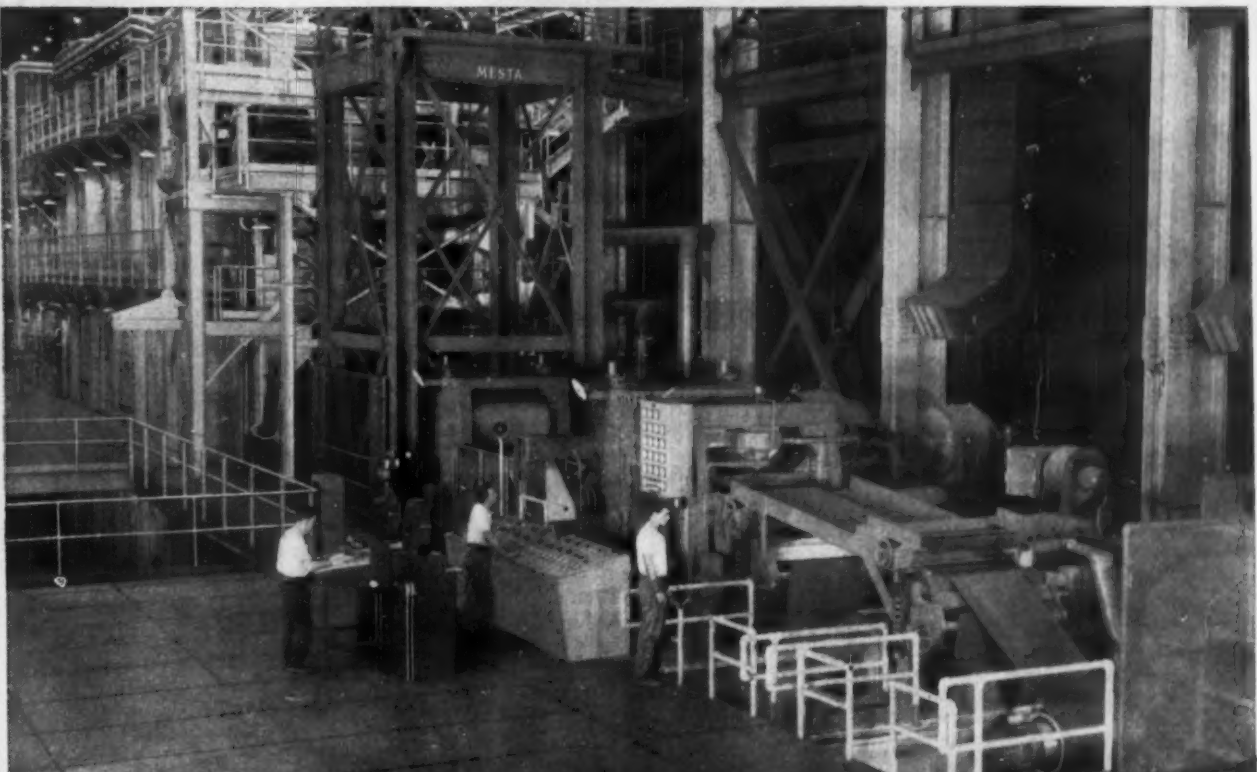

MESTA 2000 FPM Continuous Cleaning and Annealing Line for Steel Strip in Tin Plate Gauges with Pay-Off Reels, Mash Welder and Tension Reels in Operation at Weirton Steel Company, Division of National Steel Corporation.

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Re-Entry Coatings . . .

(*Continued from p. 94*)

ing environment. Furthermore, chromium, silicon, nitrogen, and sometimes carbon will increase substantially the resistance of the metallic layers to hot gas erosion and particle abrasion.

A metal with high thermal conductivity (copper, silver, aluminum and the like) applied near the bottom of the multilayer coating can remove heat and should extend the life of the part. Where localized heating is a problem, more even heat distribution will be achieved.

Using a coating with high heat reflective properties as the final layer extends the life of parts subjected to elevated temperatures from an outside source. The type of reflective coating selected should be determined by environment and temperatures encountered. Materials such as aluminum, gold, silver platinum and rhodium, protected by silicon monoxide, are some candidates for this application.

Because of their inherent porosity (10 to 15%), metal-ceramic multilayer coatings could be excellent for a sweating wall. Application of a suitable multilayer coating to a grid or screen base would allow a fluid of suitable viscosity to pass through it. This could provide protection for long times at temperatures above that for the highest melting point compound known, hafnium carbide (7030° F.). This technique can also be used in making corrosion and heat resistant filters.

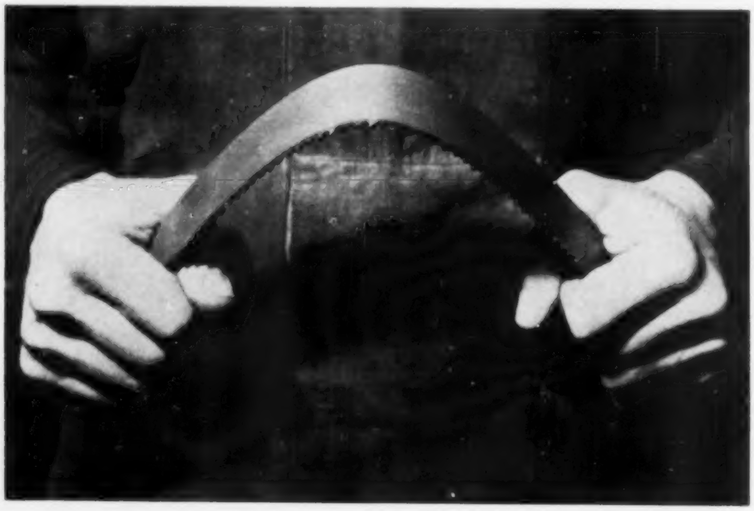
Many other variations are possible. Through proper design, laminated coatings of the metal-ceramic type can be adjusted to meet the following conditions: thermal and erosion resistance, wear and abrasion conditions, high dielectric strength, filtration medium, thermal shock, resistance to attack by corrosive fluids or gases, and surfaces capable of self-lubricity. A final coating of titanium or tungsten carbides, because of its low coefficient of friction, can provide a self-lubricating surface which is capable of satisfying many severe applications.

Although considerable data are available on the properties of the various coating materials in dense form (Table II), little is known about porous coatings. Factors to be considered include thermal conductivity, emittance at various temperatures and pressures, creep strength, corrosion resistance, erosion resistance, ductility, material stability, coefficient of thermal expansion and contraction, and abrasion resistance.

Effects of coatings on the fatigue strength should always be predetermined. Tests simulating actual operational conditions are usually a definite prerequisite.

Possible Applications

Because of its versatility and ease of application, metal-ceramic multilayer coatings have numerous possible applications other than afterburner probes, rocket blast deflectors, rocket nozzles and thermocouple protection tubes. These include rocket motor linings, nose cones, leading edges, heat treating racks, filters, high-temperature furnace linings and bearings. Recently, a multilayer metal-ceramic coating has resisted the intense temperatures



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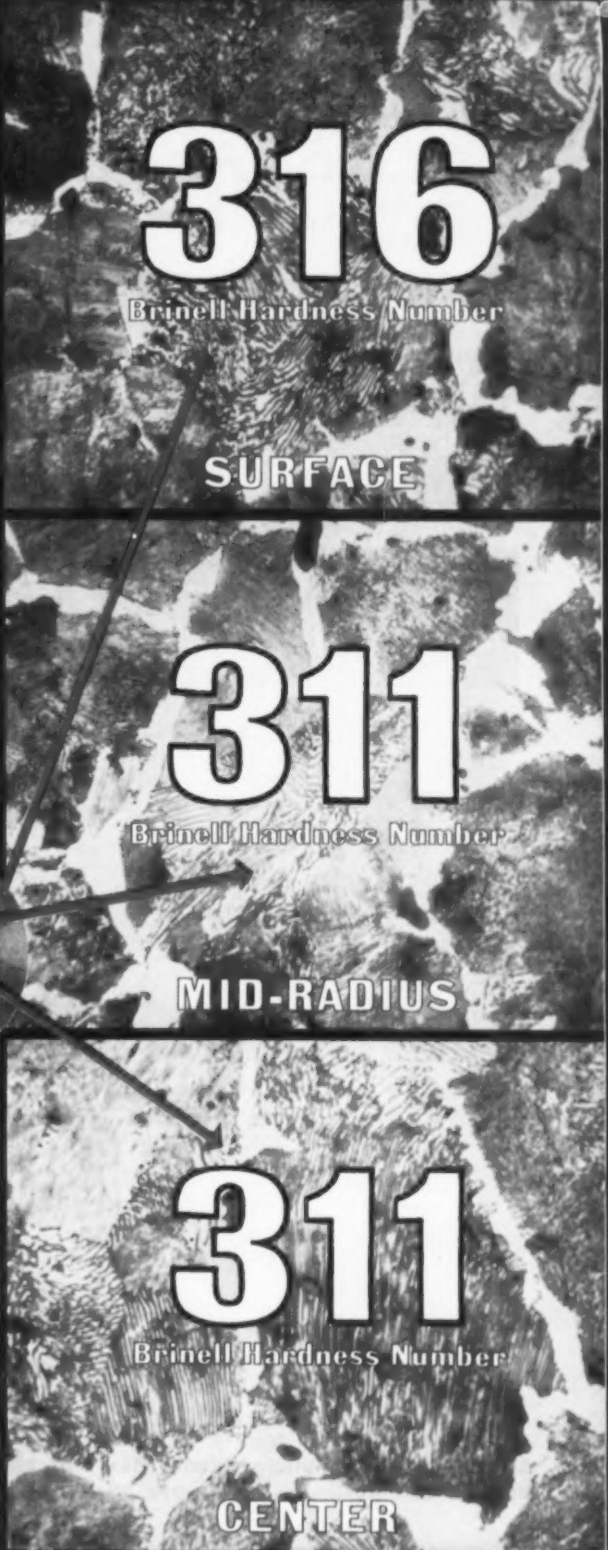

1⅜" round FATIGUE-PROOF. Magnification: 750X

The microscope shows the uniformity of FATIGUE-PROOF. Its uniformly pearlitic structure parallels its uniformity of properties from the surface to the center of the bar.

FATIGUE-PROOF strength and hardness are developed by "e.t.d." (Elevated Temperature Drawing). Unlike quenching and tempering, its effect is the same from surface to the center of the bar. It works a large bar as uniformly as it does a small bar.

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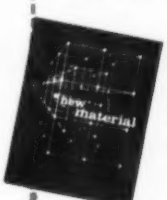

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In the Future

Solutions for many of the material problems of today and tomorrow will require cooperation between the metallurgist and ceramist. Design and material engineers also must provide help. Metals and ceramics are being united to form cermets, reinforced ceramics, and the laminated coating described here to solve many existing problems. Prestressed ceramics are also expected. The day of hypersonic space flight is a reality and man is faced with temperature problems considered insurmountable only a few years ago. When the high-temperature puzzle is reliably solved, manned space flight will be on the way to reality.

Stress-Relief . . .

(*Continued from p.* 115)

between compressive yield (71,700 psi.) and tensile yield (59,800 psi.) in the short transverse* direction. There appear to be property advantages for stress-relieved hand forgings in this respect.

In summary, both stretching and cold forging are practical, effective methods for stress-relieving aluminum products. Selection of the method must be decided for each application based on size and type of product and equipment availability. Cold forging may offer some advantage over stretching with respect to its effect on mechanical properties.

*This refers to the thinnest dimension of the part. In a plate, the test would be cut parallel to the thickness.

Welded Pipe in Nuclear Power Installations

Digest of "Fabricated Pressure Piping as Related to Nuclear Applications", by J. J. Murphy, C. R. Soderberg, Jr., H. S. Blumberg and D. B. Rossheim, M. W. Kellogg Co., New York, A.S.M.E. Paper No. 57-NESC-103, March 1957, 24 p.

THE CRITICAL DEMANDS of nuclear energy applications have intensified the need for a comprehensive basis for the design and fabrication of pressure vessels and associated piping. In this paper the authors attempt to summarize the many factors affecting the performance and reliability of pipe welds.

An important characteristic of this field of engineering is the prolific collection of safety codes and design regulations that have been adopted or imposed on pressure vessel construction and operation in the last half century. While acknowledging the necessity and value of the many existing boiler codes, pressure vessel codes and piping codes, the authors repeatedly express the opinion that these codes have not yet attained adequate engineering stature. The major codes establish only minimum quality standards and unfortunately the limitations of these codes are not always appreciated.

To improve this situation, the

Tool Steel Topics

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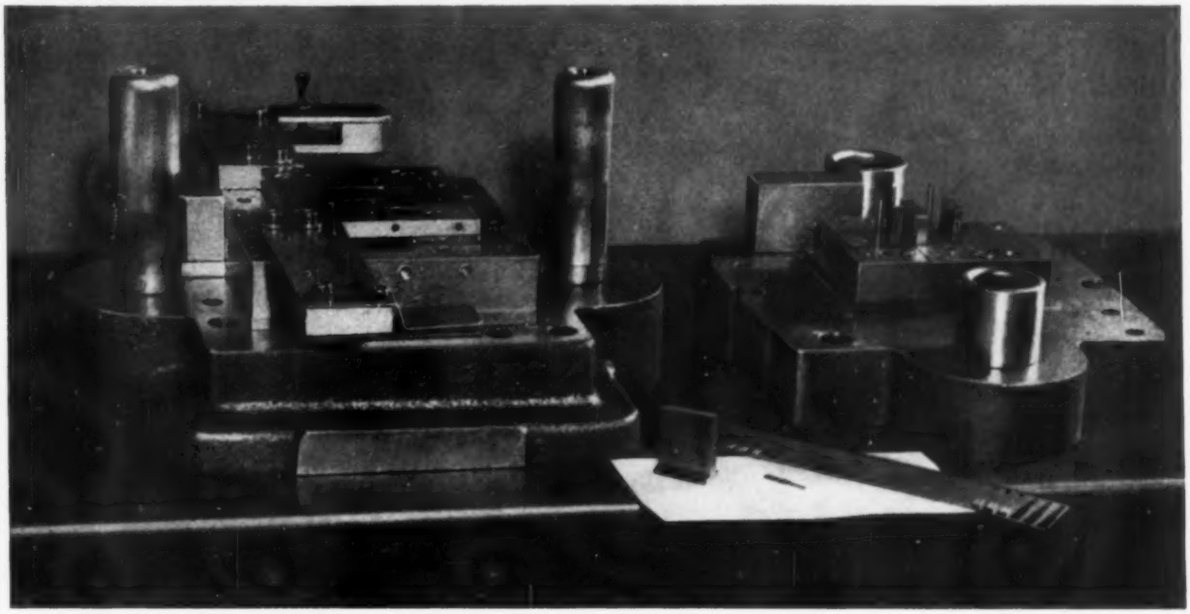

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Periodic Regrinding Improves Tool Life

The service life of many types of tools can be improved if the tools are periodically reground at intervals before they have deteriorated to a degree which impairs their function.

This practice is particularly useful when applied to tools which repeatedly fail in service by fatigue, chipping, spalling, or cracking through heat checks. The objective of preventative grinding is the removal of service-damaged metal before the damage progresses to a depth which would not be removed in normal redressing operations. It is an application of the old proverb, "A stitch in time saves nine," and is just as appropriate when applied to tools as to a small rip in a piece of wearing apparel.

The point at which regrinding should be done during the service of a given tool must be developed by experimental work. It is most practical if it can be made to coincide with a normal shutdown of an operation for other reasons.

Welded Pipe . . .

authors propose a more rigorous approach to the problem in which the many individual factors affecting the quality and reliability of a piping system are considered under four main categories as follows:

1. Design considerations.
2. Material characteristics.
3. Fabrication procedures.
4. Inspection techniques.

Overemphasis of any one of these factors is futile by itself – and hence the "level of quality" in each category must represent a like measure of refinement. Further, the desired "level of quality" must be commensurate with the hazards, the probabilities of failure and the economics of each installation. Under such complex conditions, the blanket application of simplified or minimal code rules will lead to excessive risks or costs.

After a detailed discussion of these needs and philosophies of designs, they present, in the form of a large chart, an elaborate system for classifying the requirements of welding piping systems. Four classes of systems are proposed, namely:

Class Designation	Type of Service	Type of Assembly
I	critical	complex
II	severe	complex
III	general	average
IV	nonhazardous	simple

For each of these classes, they present a "balanced" set of specified rules and procedures to be used in the design, the material selection, the fabrication, and the inspection and test of the system. The details cover calculation of allowable stresses, the use of correction factors for localized stresses and cyclic loading, the materials inspection techniques, and the erection procedures, among many others. In each respect, the severity or quality level is graduated from high to low corresponding to the original classification of the piping system.

In all, this is a commendable effort which graphically illustrates the complexity of the problem and the necessity for using some rational analytical approach. This approach is proposed in place of blind increases in the nominal safety factors of existing codes which do not properly reflect the critical demands of

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Welded Pipe . . .

our nuclear age. However, it is highly improbable that such a comprehensive change in existing codes will be quickly adopted by the various code authorities and regulatory groups.

In addition to this balanced code proposal, the authors stress the importance of paying more attention to certain critical factors such as localized stresses, thermal stresses, fatigue strength, ductility, impact resistance and corrosion fatigue in the design and construction of complex piping installations.

D. G. Ebeling

Air Melting Iron-Aluminum Alloys

Digest of "Air Melting of Iron-Aluminum Alloys", by Victor F. Zackay and William A. Goering, presented at the National Meeting of A.I.M.E., New York, February 1958.

Alloys of iron with aluminum in amounts up to 35% have many potential applications. Unfortunately, most investigators have had considerable difficulty in producing sound ingots and ductile wrought products. During the past four years, several articles have described vacuum-melting techniques which circumvent these troubles. In this publication, the authors describe air-melting procedures used successfully on heats ranging in size from 50 to 7000 lb.

Low-carbon iron is melted in a magnesia-lined induction furnace and deoxidized by an addition of 0.1% Al and 0.5% Mn. In an effort to attain a minimum oxygen level, 0.05% metallic calcium is then added in two stages. This is done by wiring small pieces of calcium to a steel rod which is plunged below the surface of the iron bath. A bath temperature of 2900° F. is recommended for this treatment. Since calcium vaporizes at this temperature, a shield is attached to the rod to protect the melter from any spattering of the material.

While the iron bath is being prepared, the aluminum is melted separately in a clay-graphite bottom-pouring crucible placed in a pot furnace at 1800° F. Hydrogen is

removed from the molten aluminum by bubbling chlorine through a quartz tube immersed in the bath for 5 min. Then, approximately 0.1% Cl is added to the aluminum.

Next, the iron bath is skimmed and covered with dried fluorspar and the molten aluminum is poured into the induction furnace. The fluorspar slag reacts with aluminum oxide formed during pouring to form aluminum fluoride. Since this fluoride is toxic, a forced draft ventilating system is required for this operation.

Because of the difference in specific gravity and because the slag-aluminum oxide reaction is exothermic, the bath should be stirred vigorously. Manual and induction stirring for at least 4 min. insures good mixing. Then the power is shut off and the bath held for 1 min. to separate the slag and metal.

After skimming, the heat is poured at 2900° F. into cast iron molds. Since iron-aluminum alloys develop deep pipes, suitable hot tops are used. The authors recommend aluminum oxide or chlorinated pitch as mold washes. Both prevent stickers but the latter gives a better ingot surface. The ingots should cool slowly to room temperature.

Various precautions minimize scrap losses from hot working. To avoid cracking from thermal shock, the ingots should be charged to furnaces at 1000° F. and heated to 1800° F. for rolling. Since the castings are tender, breakdown reductions should be small. Finishing passes on small sections can be taken at 1400° F. The schedule for reducing ⅞-in. squares to ⅝-in. rounds call for four passes at 1400°.

By such careful processing, air-melted iron-aluminum alloys were produced with tensile properties equal to vacuum-melted products.

F. W. Boulger

Germanium Rectifiers

Digest of "Semi-Conductor Rectifier Factory", *Engineer*, Vol. 205, March 7, 1958, p. 362-366.

IDEALLY, impurities in semiconductor material should be less than 1 part in 10^9 since efficiency depends primarily on the initial purity. This obviously requires very special precautions in mass producing enough germanium for high-power rectifier installations (up to at least 18,400 kw.). This is being done in a factory which maintains a high standard of general cleanliness. Air is filtered, washed and heated to maintain an even temperature throughout the factory. The building interior is specially designed with ledges and crevices minimized, windows omitted and special surface finishes. Strict regulations on clothing changes are enforced. Local protection is also provided in areas of high contamination risk.

Germanium dioxide is reduced at 700° C. (1290° F.) by furnace heating in hydrogen. When reduction is complete, hydrogen is replaced by inert atmosphere with further heating to 1000° C. (1830° F.), followed by slow cooling and solidification. This ingot is placed in a pure graphite boat within a tube containing argon for zone refining. Purity is checked by measuring bulk resistivity of pure germanium.

Refined polycrystalline germanium is placed in a quartz crucible with additive impurity and heated in a graphite pot in argon. A seed crystal with its end cut at right angles to a crystal axis is lowered vertically into the melt. The shaft holding the seed rotates at about 2 rpm. with simultaneous withdrawal of a few inches per hour. Temperature must be (and is) controlled within 1° C. Single crystals as large as 5/8 in. diameter and 15 in. long can be produced. After cutting into 1-in. sections and checking, the crystal is cut to a square cross section. Slicing is done by tungsten wire carrying fine abrasive dust in suspension. Each wafer, after inspection for flatness, surface finish and thickness, is the basis for a rectifying cell.

Assembly of the rectifier cell requires a sequence of mechanical operations alternating with cleaning operations, all performed under conditions of surgical cleanliness. All operations such as washing, etching and soldering make full use of hoods and fume extractors. Clean, dry operations are performed in dry glove boxes.

A germanium wafer, 0.4 in. square and 0.025 in. thick, is cleaned and soldered in inert atmosphere to a wafer base. A pellet of pure indium is cleaned, placed on the wafer, and belt conveyed through a furnace, having a maximum temperature of 600° C. (1110° F.), in an argon atmosphere, where it fuses with germanium to form a *p-n* junction. This basic unit then is soldered to a base electrode.

Although this unit is a rectifier, it requires removal of some impurities in the surface layer of the fused junction by electrolytic etching to avoid further contamination.

After careful washing and vacuum drying, the unit is not touched by hand nor removed from the clean at-

Germanium . . .

mosphere until it is hermetically sealed in a capsule. Before sealing, its electrical characteristics are measured, a flexible upper conductor is attached by soldering, and it is fitted in the capsule. After sealing, the cell can be handled with impunity. It is then graded, painted, and classified by its electrical performance.

C. O. SMITH

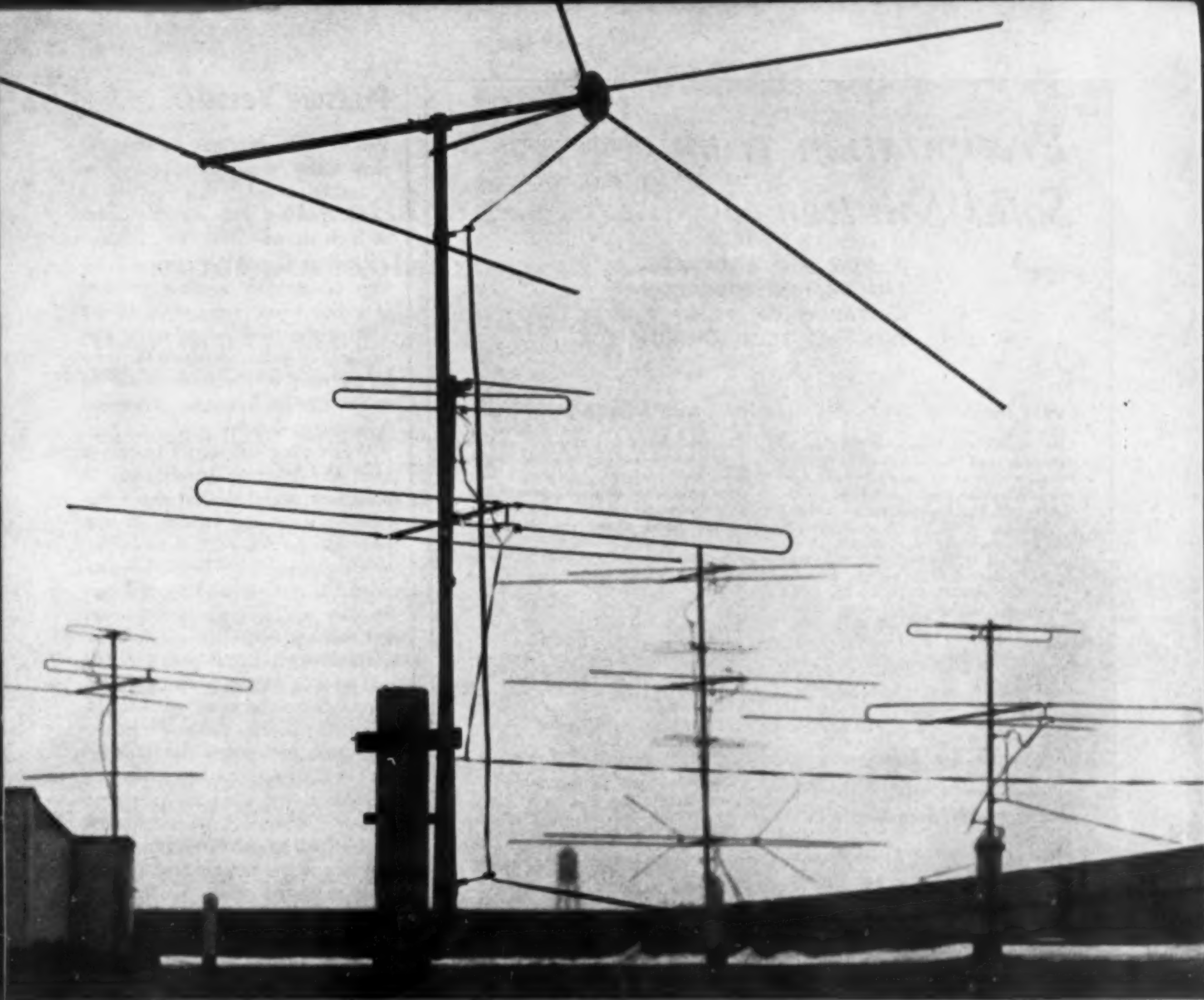
Proof-Testing Pressure Vessels

Digest of "Proof-Testing Pressure Vessels Designed for Internal Pressure", by R. W. Schneider, *Bulletin*, Welding Research Council, No. 38, July 1957. 8 p.

THIS PAPER analyzes data obtained from various proof-tests used to establish a safe working pressure for pressure vessels. The tests are described in the A.S.M.E. Boiler and Pressure Vessel Code, 1956 Edition, Sec. VIII, Unfired Pressure Vessels.

The significance of the data obtained in the brittle coating test depends upon the sensitivity of the lacquer used. High-sensitivity lacquers are associated with small or elastic strains and low-sensitivity lacquers with large or plastic strains. High-sensitivity lacquers indicate the strain in one direction if the sensitivity of the coating is known. They also show the direction of principal stresses and the areas of maximum strain. However, if a low-sensitivity lacquer is used, the pressure at which the coating indicates stress coincides with complete plasticity for the first point on the vessel to attain the completely plastic state when the material is not work hardenable. This test may be used only for materials having a definitely determinable yield point.

In pressure vessel design the safety factor – ratio of the ultimate tensile strength to the stress selected for design purposes – is usually five or four. However, secondary stresses may exist and the actual stresses may exceed the specified design stress by a factor of three or more. There exists little, if any, correlation between design stress or safety factor and the bursting pressure of the vessel.



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Pressure Vessels . . .

Failure does not alway occur in the most highly stressed areas except in a brittle material; consequently a destruction test may not show areas of high stress.

Caution should be exercised before adopting a working pressure at testing temperature equal to one fifth of the bursting pressure, particularly in instances where the service pressure or temperature will be cyclic with possible attendant fatigue-type failures.

When a high-sensitivity lacquer is used for determining the areas of maximum strain, the pressure coincident with initial yielding at that point can be defined if there are no bending stresses. When a low-sensitivity lacquer is used for the preliminary test, a strain measurement test will not define the pressure coincident with initial yielding but will give a higher pressure which approaches or becomes equal to the complete plasticity pressure because, during the preliminary test, the vessel has been subjected to a pressure coincident with complete plasticity. However, if strain gages are applied to a second vessel of identical construction at the point where the lacquer indicated strain on the first vessel, the pressure coincident with initial yielding can be determined, provided that the second vessel has never been previously subjected to pressure and overstrained. Whether a low or high-sensitivity lacquer is used in the preliminary test, it is possible to calculate the maximum error between the measured stress and the maximum stress possible in the port or vessel.

The displacement measurement test may be used only for vessels and vessel parts constructed of material having a definitely determinable yield point. In theory, this test produces the same data as the strain measurement test. However, additional errors are likely to occur because it is almost impossible to read displacement with deflection dial indicators with the same accuracy as electric resistance strain gages. Furthermore, if there are any localized areas of high stress in the material, the radial displacement may be so small as to make this test unreliable.

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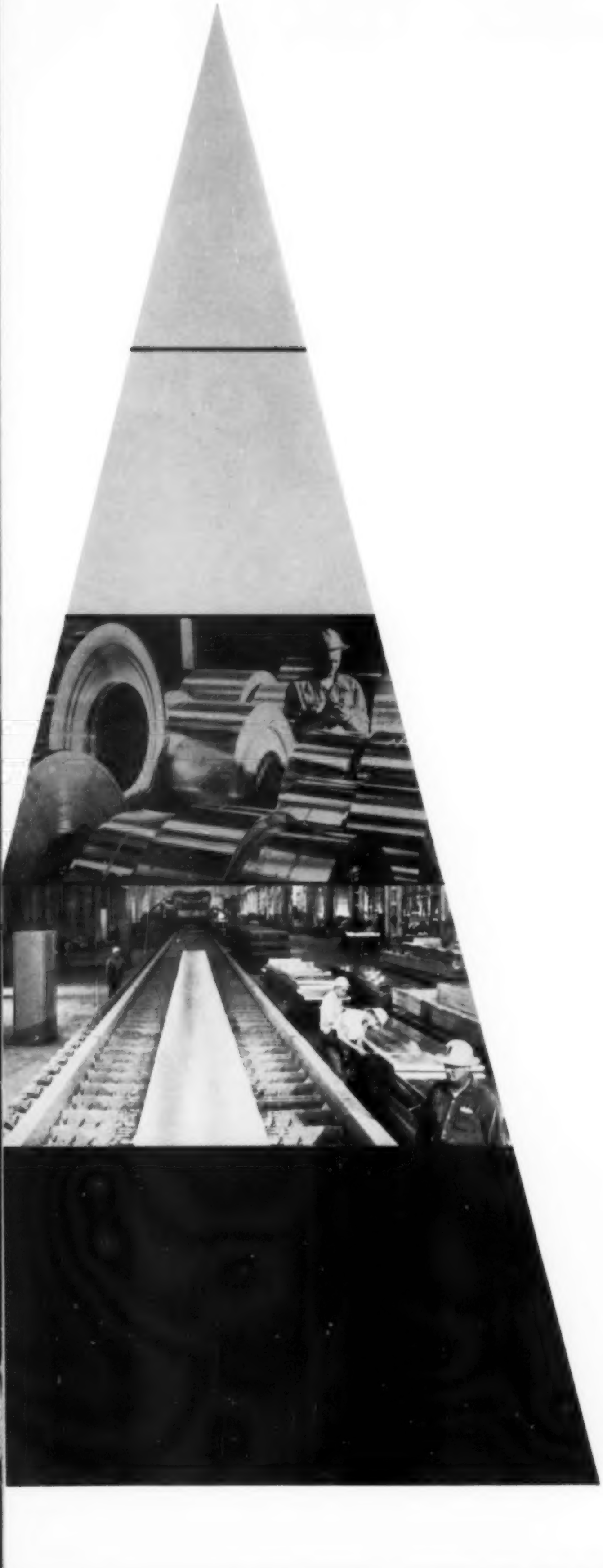


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Effect of Nozzle Shape on Pouring Stream

Digest of "Effect of Nozzle Characteristics on Steel Pouring Streams", by R. E. Stoll and E. C. Rudolphy, U.S. Steel Corp., Chicago. Paper presented at the 41st A.I.M.E. Openhearth and Blast Furnace Conference, Cleveland, April 1958.

THE NOZZLE DESIGN, nozzle material, and operating variables affect the shape and pattern of the stream which, in turn, affects the ingot quality. Flared, irregular streams, for example, are detrimental to both surface quality and cleanliness. For years, various investigations have been made: This one discusses development of a tapered nozzle (see Fig. 1) for the intermediate pouring ladle (also called a basket). It gives a much smoother, less turbulent stream than does the standard straight-sided nozzle. Studies are being made on the use of this type of nozzle in openheath and electric furnace ladles.

Fig. 1 – Tapered Nozzle Eroded by Molten Steel. Dotted lines indicate original outline

Work was initiated by the construction of a laboratory model of the basket which contained two openings so that streams from the standard and experimental nozzles could be compared under similar conditions. The streams were photographed by slow-motion cameras,

and the films rated by laboratory personnel. The standard sharp-shouldered nozzle emitted a spiral stream which was quite turbulent. Several design changes were tried; since the tapered, or "converging bore", nozzle was the most successful at reducing eddy currents and turbulence, it was chosen for the production trial. The orifice diameter of the nozzle was set at 1½ in. and the diameter at the base of the seat at 2½ in.

Results of the production trial indicated that the tapered nozzle produced less turbulence and flaring than did the standard one. Further, the pouring rate was more uniform though slightly higher. By varying the seat and orifice diameters, any pouring rate can be obtained. Tapered nozzles did not accumulate a bore build-up, were not difficult to open up, and required less oxygen to keep open. Refractory and iron oxide inclusions were also reduced. These advantages resulted in the adoption of the tapered nozzle for all basket pouring operations.

Nozzle refractoriness was tested at three levels: low, represented by pyrometric cone equivalent 16 (2715° F.), medium, pyrometric cone equivalent 23 (2920° F.), and high, pyrometric cone equivalent 29 (3020° F.). Using standard fireclay nozzles, the basket was again selected for production tests. The "medium" nozzles gave the best performance since the "low" ones eroded too fast giving a flaring stream, while the "high" ones had too great a build-up of chills around the orifice. A nozzle refractoriness range of pyrometric cone equivalent 16 to 23 is now specified with the high side preferred.

Alumina and zirconia nozzles were also tested as were fireclay nozzles impregnated with oil or tar. Impregnation had no effect, while the alumina and zirconia nozzles gave extremely poor performance. Excessive chill build-up was responsible for this. Supplementary work showed, among other things, that simultaneous pouring from ladle to basket and from basket to mold created considerable turbulence in the basket. A flared stream results and surface quality drops.

Basket pouring is, of course, a minor part of general pouring operations. It was chosen for experimental work chiefly because the

Nozzle Shape . . .

ferrostatic head remains essentially the same throughout the pouring cycle. As ingots are poured from the large electric furnace and open-hearth ladles, the ferrostatic head constantly decreases; this added variable complicates adaption of the tapered nozzle to these ladles. Work is now proceeding in this direction.

C.R.W.

Recording Torque-Twist Measurements for Wire

Digest of "A Recording Torsion Testing Machine for Wire", by H. C. Burnett, *A.S.T.M. Bulletin*, No. 227, January 1958, p. 68-69.

A MACHINE for automatically recording torque-twist measurements on wire of less than 0.05 in. diameter has been designed and constructed at the National Bureau of Standards in Washington, D.C.

The general features of the machine and the recording section are shown in Fig. 1 and 2, respectively. The test specimen (A) is surrounded by a cylinder of heat-sensitive paper (E) attached to a disk mounted at the top of the test wire. This paper hangs between a moving knife-edge bar electrode (D) and a fixed knife-edge electrode (F) without touching either. The knife edge is used to confine the

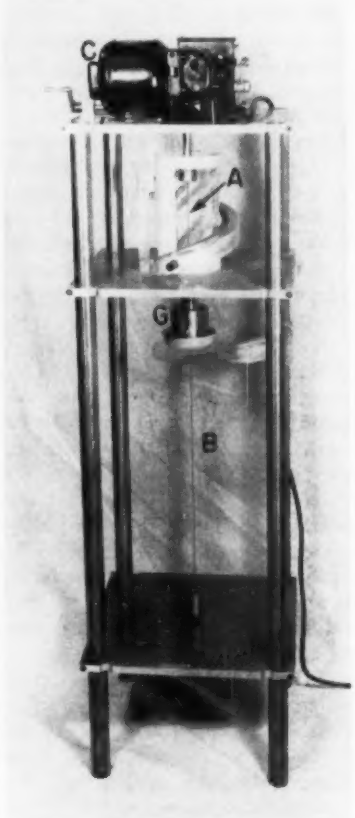

Fig. 1 – Torsion Testing Machine for Small Diameter Wire. A, specimen; B, torque measuring wire; C, motor and reduction gear assembly; G, damping cup

origin and increase the intensity of a spark supplied by an ignition coil and an interrupter. Sparks passing through the paper from the fixed to moving electrode make a line of dots to record the torque-twist relationship. Applied torque is proportional to rotation of the moving electrode and is recorded by the vertical displacement along the fixed electrode.

Torque-Twist . . .

Twist is measured by the difference in rotation of the recording paper and the moving electrode.

No special specimen preparation is required other than cutting and bending specimen ends 90° with the desired test length between them. Machine setup is rapid and relatively simple with ready adjustment to desired zero-load position. Flexibility in design allows for various test lengths and torque ranges. A variety of loading sequences is possible by incorporation of a forward-neutral-reverse arrangement in the reduction gear assembly.

Torque-twist data including load-permanent set and twist-permanent set are readily obtained. Even small torques can be recorded accurately since the recording arrangement is frictionless. The machine has additional advantages of low first cost and lack of complicated accessories. C. O. SMITH

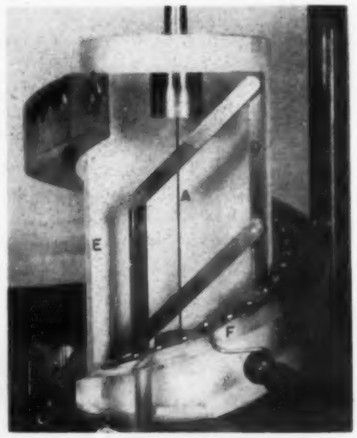

Fig. 2 – Recording Section of Torsion Testing Machine

Shallow Carburized Case Depths

Digest of "Nondestructive Determination and Control of Shallow Carburized Case Depths", by Romeo Suffredini, *A.S.T.M. Bulletin*, July 1957, Vol. 223, p. 74-78.

THE CORRELATION between the depth of shallow carburized cases and their surface hardness was investigated. From this correlation, a test was developed for determining and controlling the case depth on rifle and shotgun parts.

Flat test specimens of A.I.S.I. C 1010, B 1112 and C 1120 were carburized to various depths up to approximately 0.010 in. The carburizing treatments were carried out at 1550° F. in a salt bath containing 20.5% cyanides. Treatment times ranged from 5 to 60 min. Ten specimens of each steel were carburized for a given time. Five of them were quenched in oil and the other five in water. All specimens were tempered at 350° F. for 20 min. Their hardness was then determined. The specimens were again tempered at 600° F. for 20 min., another hardness survey was made and this was repeated after tempering at 750 and 850° F.

The hardness tests were made on a Rockwell superficial hardness tester with the N-15, N-30 and N-45 scales. The reported values are averages of at least ten determinations on each scale. The measured surface hardness did not result from the case alone but was

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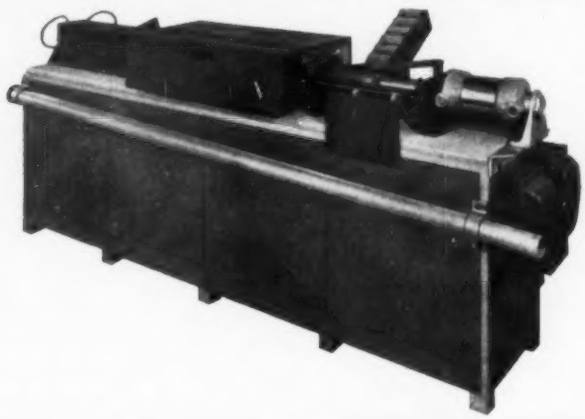

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Selected Values of Superficial Rockwell Hardness of A.I.S.I. C 1120 Carburized in Liquid Bath at 1550° F. and Tempered

Case Depth	Water Quenched and Tempered at 350 or 750° F.						Oil Quenched and Tempered at 350 or 750° F.					
	15N		30N		45N		15N		30N		45N	
	350° F.	750° F.	350° F.	750° F.	350° F.	750° F.	350° F.	750° F.	350° F.	750° F.	350° F.	750° F.
None	77	76	52	51	38	36	64	61	30	30	<20	<20
0.001 In.	80	77	59	55	43	38	64	63	30	30	<20	<20
0.002	83	80	64	60	44	39	66	66	36	34	<20	<20
0.003	85	83	67	63	52	43	72	70	41	37	<20	<20
0.004	87	85	71	65	55	46	77	75	48	41	21	21
0.005	88	86	73	66	58	49	82	80	55	47	28	27
0.006	90	87	76	67	61	51	85	81	60	52	33	30
0.007	91	88	78	68	63	53	87	84	65	57	35	35
0.008	92	88	80	69	65	55	90	86	69	62	45	39
0.009	92	88	81	70	68	56	91	87	72	65	52	42
0.010	93	88	82	71	75	57	91	87	76	67	57	44

also affected by the hardness of the core.

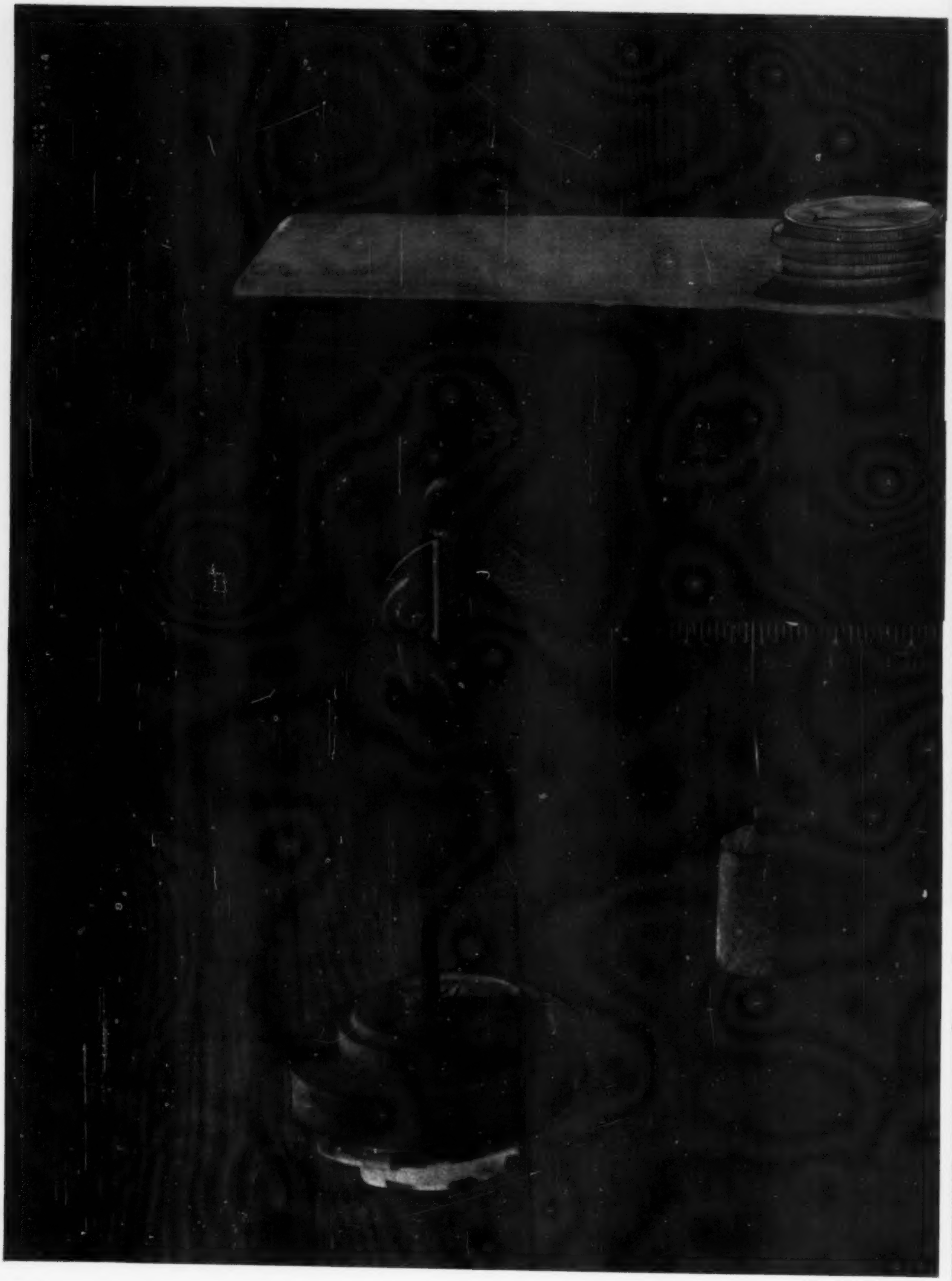
The case depth of each specimen was measured by five or more microscopic determinations. The distance between the outer edge of the case and the first indication of free ferrite was defined as the "case demarcation line".

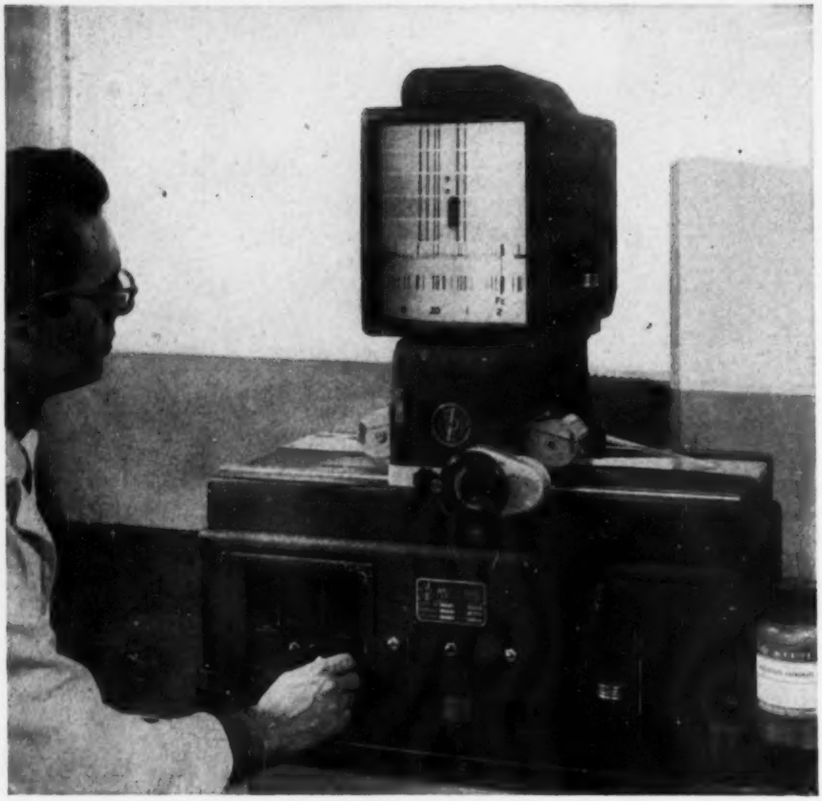
As a check on the metallographic determination of case depth, Knoop microhardness traverses were made across the cases of randomly chosen specimens. The microhardness gradients leveled off to the core hardness at a depth greater than the case depth indicated by the demarcation line. The hardness of the case at the demarcation line was dependent both on the hardenability of the material and the heat treatment it received.

Superficial Rockwell hardness values were recorded against case depth for the three steels and eight heat treatments. The table presents for one steel selected values which illustrate the relation between surface hardness and case depth. As can be seen in the table, the values measured on a given hardness scale do not change significantly with case depth in all ranges. The sensitive ranges depended on the heat treatment and the steel. The appropriate hardness scale must, therefore, be selected for determining the case depth under given conditions.

The author concludes that Rockwell superficial hardness values can be used as a nondestructive test for control of the case depth of liquid carburized cases. He considers this test superior to fracture testing and microscopic examination with respect to cost involved, time of test and reproducibility.

Michael B. Bever





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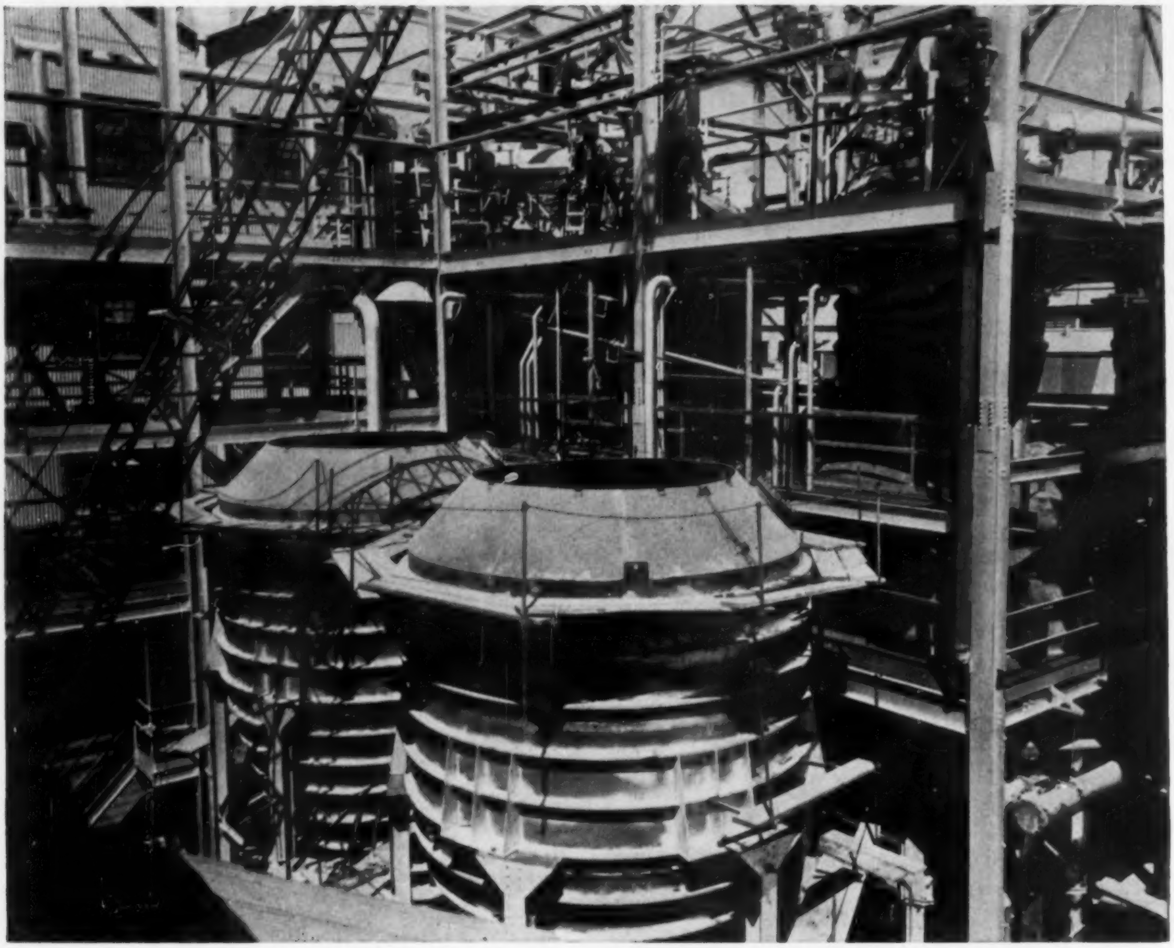

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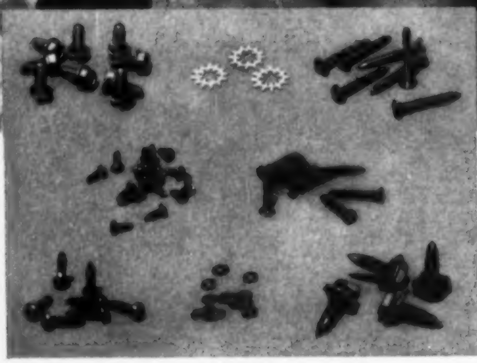

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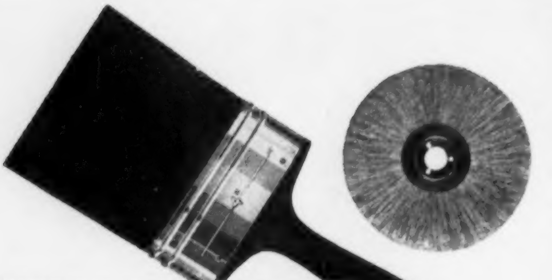

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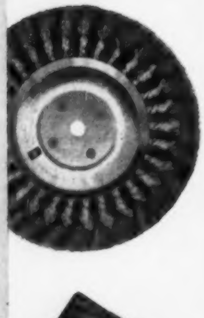

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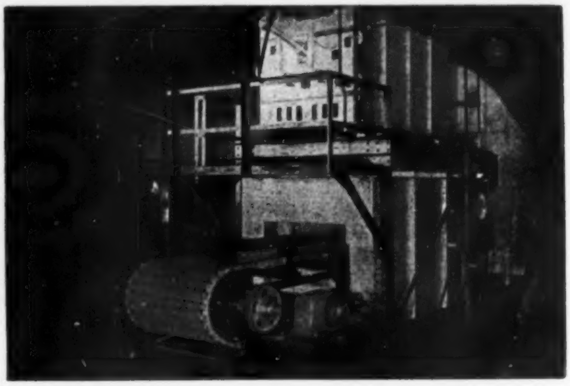

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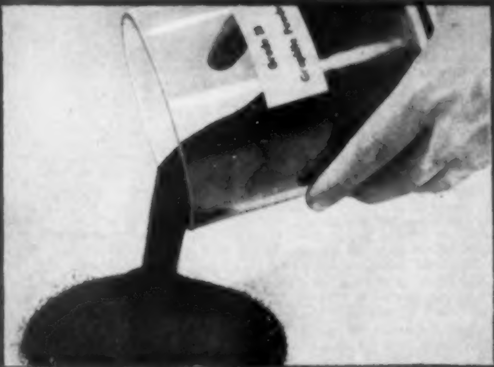

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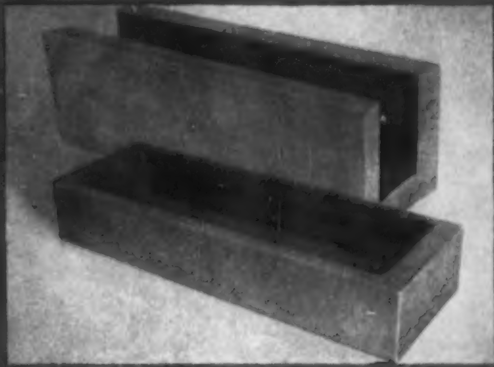

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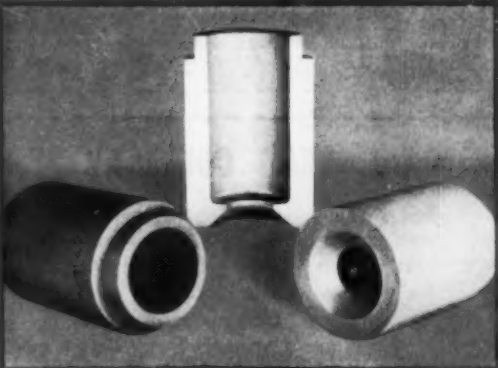

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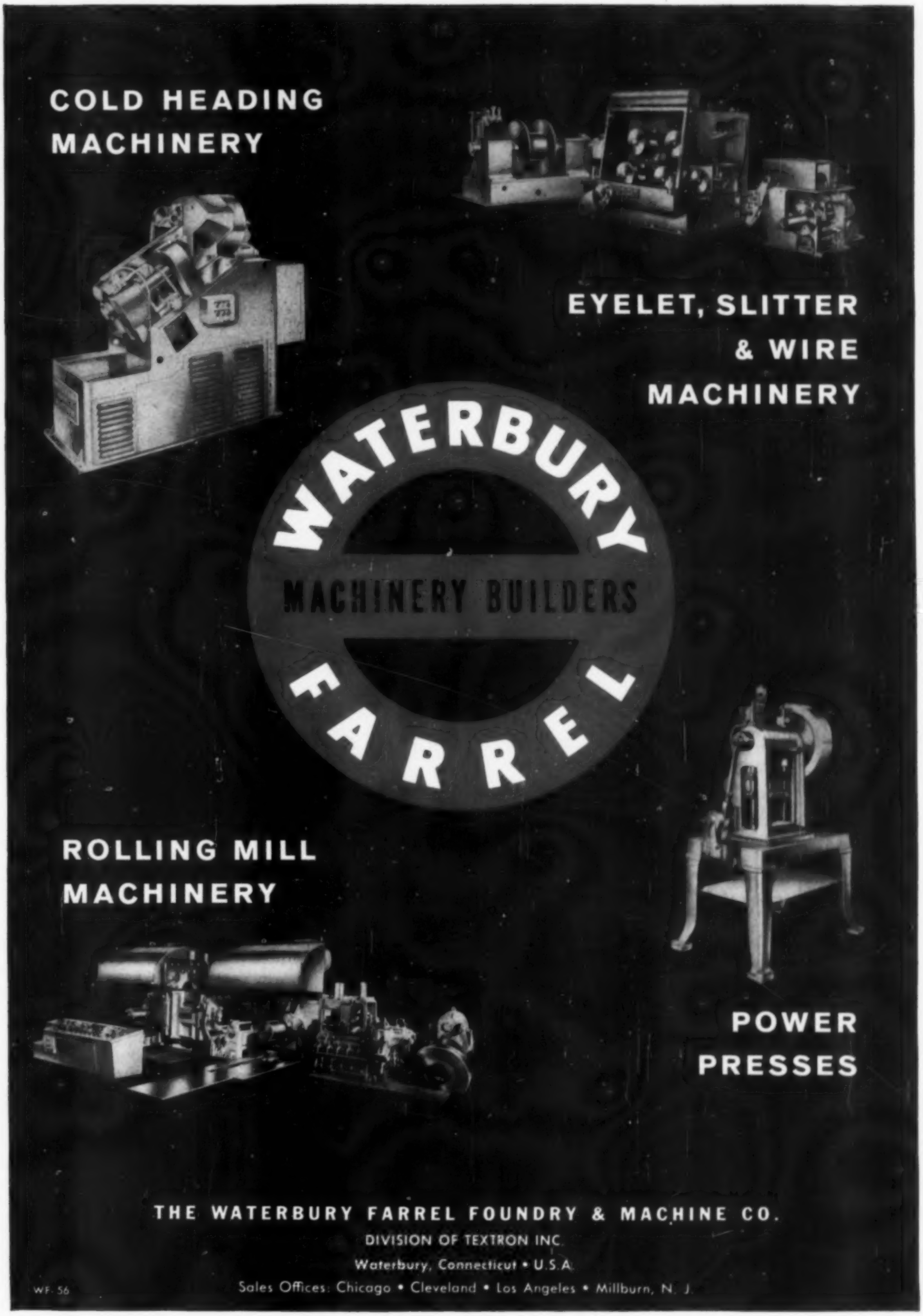
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